California Solar Initiative RD&D Program

Process Evaluation

Final Report

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Executive Summary

The California State Legislature created the California Solar Initiative Research, Development, Demonstration and Deployment Program (the CSI RD&D Program, or the Program) in 2006 to support the broader California Solar Initiative. The CSI RD&D Program received $50 million to fund research, development and demonstration projects supporting integration of distributed solar photovoltaic (PV) into the California grid, with the longer-term goals of increasing solar technology performance, reducing solar technology costs, and filling technical knowledge gaps in the solar industry.

The CSI RD&D Program design established three target research areas:

- **Grid Integration:** Improving PV integration with transmission and distribution systems (50-65% of funding).
- **Solar Production Technologies:** Supporting commercialization of new PV technologies (10-25% of funding).
- **Business Development and Deployment:** Supporting the market and end-users (10-20% of funding).

The CSI RD&D Program funded 37 projects (35 of which were completed) across the three target research areas, with total CSI funding of $38.3 million in addition to $34.6 million in matched funding from the grantees and other sources.

In 2016, Evergreen Economics led a research team consisting of Evergreen Economics, Research Into Action, Dr. Gretchen Jordan, Dr. Varun Rai, and Advanced Survey Design to conduct a process evaluation of the CSI RD&D Program. This theory-based evaluation began with the development of a program logic model that linked the CSI RD&D Program activities to immediate outputs and to longer-term outcomes that were consistent with California Public Utilities Commission (CPUC) policy goals.

Once the Evergreen team identified metrics that would provide evidence of the Program's progress toward its goals, the evaluation team developed a data collection plan to gather information from a variety of different activities:

Primary data collection activities for the evaluation included:

- Compiling Program and project data and documentation
- In-depth interviews with grantees and program managers
- In-depth interviews with industry experts and stakeholders
- In-depth interviews with market actors
- Survey of market actors

- External data/literature

In addition to the data collection and analysis, the Evergreen team completed a related network analysis task to evaluate the knowledge benefits provided to the solar community as a result of Program activities.

Based on these research activities, general conclusions from the evaluation are summarized below.

1. **The Program Manager Itron performed very well.** Grantees receiving funds from the Program gave universally positive feedback on Itron. Itron carried out all the required tasks of the Program Manager very competently and implemented the Program in accordance with the original Program design. Itron communicated clearly with grantees and stakeholders throughout the life of the Program, completing each phase – proposal solicitation, project selection, project implementation oversight, and final reporting – with no complaints and with high satisfaction ratings from participants. Itron also played an important and highly effective role in facilitating communication and partnerships within and between projects, as well as with the broader solar community, helping to engage key stakeholders and reduce duplication of efforts.

2. **CSI RD&D projects were mostly successful in making progress toward the long-term policy goals established for the Program.** Demonstration of short-term outcomes that are consistent with the logic model is a positive sign that projects are on a pathway to achieving the longer-term goals established for the Program. Examples of successes for each of the project groups (with details included in the full evaluation report) are summarized below.

    - ***Grid Integration*** was the most successful research area, with 20 completed projects. Important accomplishments for these projects included the following:
        - **Improvement to interconnection requirements.** There are a host of rules and regulations governing the interconnection, operating, and metering requirements for solar generating facilities connected to the distribution system. Eight of these projects conducted work explicitly designed to influence standards or rules relating to interconnection. Specific improvements addressed PV interconnection limits, project screening, and costs and processes for energy storage systems. These changes helped streamline the review process for interconnection and storage projects, and played a direct role in the improvement to the interconnection process in California.
        - **Software products.** Across the 20 projects with Grid Integration components, there were over 30 outputs that included commercialized software packages,

modeling methodologies, open source modeling tools, data collection tools, and databases. Grantees developed several software products that improve resource visibility, provide more accurate prediction of generation, and allow grid planners to model the economic value of planned solar generation resources. Improvements in these areas add to overall system reliability, particularly in situations with high penetration PV.

  - **Improved modeling tools.** Aside from specific software applications, several projects developed modeling tools and methodologies that can be adopted or integrated into existing utility planning and operations tools. These included tools for solar irradiance forecasting, generation forecasting for individual systems and fleet systems, distribution system models, and economic value modeling tools. Each of these can be used to improve system reliability through more accurate prediction of solar generation and optimal siting of generation resources.
  - **Inverter system enhancements.** Advanced smart inverters are communication-enabled inverters that can improve communication between distributed solar resources and the grid. Improvements to inverter systems can greatly increase the penetration of PV and other renewable energy on the grid. Key accomplishments by the Program in this area included demonstration projects of advanced smart inverters, technical reports providing guidelines and inverter settings, and studies to develop optimal control methods.
  - **Permanent demonstration sites.** The Grid Integration research area accounted for six demonstration sites. Examples of these projects include demonstrations of battery packs, a showcase home for Zero Net Energy homes and their integrated technologies, a training facility, and a field demonstration of a PV penetration modeling tool.

- The ***Solar Production Technologies*** research area had a total of 12 projects, with varied success. While most of these projects met all their stated objectives, some either did not meet their objectives or invested in technology that proved not to be viable in the market at present. Significant accomplishments with this research area included:
  - A project between SolarCity and Tesla demonstrating new battery technology and control systems that led directly to development of the Tesla PowerWall product, which was predicted to have in excess of 168 MWh in sales ($44 million in revenue).
  - A project by Sunlink involving seismic testing and design automation of solar mounting units. This led to Sunlink developing new software to improve design and reduce costs of mounting products, as well as a new startup company that created automated design software.

- The ***Business Development and Deployment*** research area included 10 projects and had the least success, both in terms of achieving the stated project goals as well as in demonstrating short-term progress on key metrics. There were positive contributions from this group, however, including two technology projects that did develop business models and strategies that have proved successful. These have helped support expansion of cost-competitive solar technologies, either by reducing costs or increasing value of the solar and storage technology to owners and utilities.

3. **The Program resulted in a substantial amount of knowledge benefits**. The creation and dissemination of knowledge benefits may be the most important metric of success when evaluating a research program. By this measure, the CSI RD&D Program was very successful and took an essential step toward achieving its longer-term program goals. Key examples of successful knowledge benefits include the following:

    - **The Program research has been widely cited.** A primary knowledge benefit is the degree to which research results are cited in the related literature, as this reflects its potential value outside the Program. In this regard, the Program has been very successful, with 395 total citations to date. Among the 153 papers and reports publicly released by Program teams, 26 have been cited at least one time.
    - **Collaborative team dynamics led to significant follow-on research, with more than 40 enduring partnerships resulting from the Program**. Continued research activities combined with new and sustained partnerships are positive effects of the Program and provide another solid indicator that the Program is on a pathway to achieve its longer-term policy goals. As a result of the Program, a variety of partnerships were formed among team organizations, between team organizations and stakeholders, and between team members and market actors.
    - **The Program design led to the selection of teams committed to knowledge transfer.** Most teams went beyond the minimum knowledge exchange activities required by the Program, and many created additional knowledge dissemination opportunities by releasing resources freely to the public and by developing demonstration sites. Teams identified direct stakeholder engagement, non-Program webinars, and conference presentations as the most effective knowledge exchange methods.

While the CSI RD&D Program was generally successful on multiple fronts, the results of the evaluation did yield some recommendations for future programs.

- **Sustained program documentation.** Some stakeholders and grantees indicated concern that the Program results have not been disseminated broadly enough and are concerned that the CSI website may not continue to be maintained in the future. The present plan is for the CSI website to remain functional in its current form until December of 2019. We recommend that when the current website is deactivated, the current website contents (including final reports and project documentation) be moved to another established website such as www.calmac.org so that access to the research results can continue.

- **Dissemination of Program results.** There is evidence that some CSI RD&D research has not reached the intended audiences. Two audiences in particular proved challenging: solar hardware and installation firms, and commercial organizations (e.g., builders, retail). To address this, some form of promotion or dissemination of program knowledge in aggregate should be considered—for example, engaging grantees or stakeholders with project knowledge to make presentations at conferences or to key working groups, or write articles in industry publications that summarize key research findings and direct readers to the Program website.
- **Program management.** The Program Manager Itron was very successful because it had sound technical knowledge and key industry contacts that allowed it to provide meaningful assistance and make critical networking connections that enhanced program success. Future RD&D programs should have similarly qualified program managers who can provide these types of benefits.
- **Reporting.** We received consistent feedback from the grantees that the reporting requirements were too demanding and difficult to coordinate. To address these concerns, future programs should consider modifying the reporting requirements to be more flexible. Other suggestions from the grantees included providing a report template early in the process, encouraging more stakeholder involvement, and making some draft reports public to elicit more feedback.
- **Best Practices manual.** There are several aspects of the program design that were critical to the success of the Program including careful consideration of project team composition, knowledge dissemination requirements, built in networking channels and events such as webinars and forums. If there are future RD&D efforts being considered by the CPUC or other agencies, consider working with Itron and CPUC staff to develop a best practices manual that captures the successful elements of program design and management based on the CSI RD&D Program experience.

1 Introduction

The California Solar Initiative Research, Development, Demonstration and Deployment Program (the CSI RD&D Program, or the Program) was created in 2006 with the passage of Senate Bill 1 (SB1) to support the broader policy goal of installing 3,000 MW of distributed solar by 2016 and placing distributed solar photovoltaic (PV) on 50 percent of all new homes in California by 2020.[1] As part of this effort, the California legislature authorized the California Public Utilities Commission (CPUC) to allocate $50 million of the CSI budget to the RD&D Program. The RD&D portion of the CSI Program was dedicated to funding research and demonstration projects with an emphasis on supporting integration of distributed solar PV into the grid, increasing solar technology performance, reducing solar technology costs, and filling technical knowledge gaps in the solar industry.

The establishment of the CSI RD&D Program in 2006 was timely, with installed distributed generation solar capacity growing more than ten-fold from approximately 350 MW in 2008 to over 4,500 MW by the end of 2016.[2] This rapid growth in installed capacity raised important concerns about the potential for California's electricity grid to integrate such high levels of penetration, increasing the relevance and need for research conducted through the CSI RD&D Program.

The CSI RD&D Program began soliciting proposals for projects in 2008, and between 2010 and 2014, funded 37 projects over five grant solicitation rounds.[3] The Program ran for eight years with the last project completed in December of 2016. To meet the focus of the Program as envisioned in SB1, the Program required that projects concentrate on four research areas:

- Grid integration, storage and metering;
- Production technologies;
- Business development and deployment; and
- Cross cutting (covering several research areas)

Of the 37 projects accepted by the CSI RD&D Program, 35 reached completion, and 2 were cancelled. Across the 37 projects, $34,177,809 in CSI funding was delivered, with project partners providing $30,839,909 in match funding.

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[1] *Senate Bill 1* (Murray, Chapter 132, Statutes of 2006). http://www.energy.ca.gov/sb1/

[2] California Distributed Generation Statistics. http://californiadgstats.ca.gov

[3] In addition to the 37 CSI RD&D projects, the CSI RD&D Program also provided $10 million in funding for the Solar Energy Research Center (formerly Helios), a 39,000-sq. ft. research facility on the University of California, Berkeley campus. This research center is not addressed in this evaluation.

In January of 2016, the CPUC selected the Evergreen Economics team (the Evergreen team) through a competitive bidding process to conduct a qualitative evaluation of the CSI RD&D Program. The Evergreen team consisted of the following firms:

- **Evergreen Economics**, as the prime contractor, took the lead in designing and managing all evaluation activities and was the prime author of this evaluation report.
- **Research Into Action** assisted with the evaluation design and implementation of all data collection activities. Research Into Action also designed and conducted the network analysis and the estimation of knowledge benefits, two critical components of the evaluation.
- **Dr. Gretchen Jordan** of 360 Innovation assisted with the development of the program logic model and data collection plan.
- **Dr. Varun Rai** from the University of Texas-Austin provided assistance with the network analysis and estimation of knowledge benefits.
- **Advanced Survey Design** contributed to the data collection and analysis activities.

The overarching objective of the evaluation was to determine the effect of the CSI RD&D Program on the growing distributed solar market in California. To achieve this broader objective, the CPUC established specific research goals for the evaluation that included measuring the following:

- The sizes of the grants obtained from CSI RD&D funds;
- The benefits for California ratepayers;
- The economic value to the California grid;
- Whether and how the project expanded PV market opportunities or reduced barriers;
- Leverage from other funding sources (use of match funds);
- Institutional and regulatory acceptance of project findings or outcomes (technology transfer and follow-on use); and
- Clean jobs created through CSI RD&D funding.

The Evergreen team designed a theory-based evaluation appropriate for an RD&D program that addressed each of these research objectives, as well as additional issues identified through the program logic model.

The remainder of this evaluation report is structured as follows. First, the program background and project accomplishments are summarized to provide context for the evaluation. Next, the evaluation methods are discussed followed by a section presenting the CSI RD&D Program logic model. An assessment of overall program management is presented in the following section. Separate sections are then included that discuss the program accomplishments in each of the research pathways identified in the logic model. The report concludes with a section on evaluation conclusions and recommendations.

Given the complex and technical nature of both the CSI RD&D projects and the theory-based evaluation of program accomplishments, the main report sections are intended as a narrative summary of the evaluation results. Additional detail is relegated to multiple appendices that are included as a separate volume to the main report.

2 Program Background

2.1 Program Overview

In 2006, California's total cumulative capacity of installed distributed solar photovoltaic (PV) was approximately 150 MW, meaning a target of 3,000 MW would require a twenty-fold increase in installed solar PV.[4] An increase of this magnitude caused significant concern among California utilities, grid operators, and other stakeholders, as there was little knowledge about the potential impacts on the grid from such high levels of solar PV installations. In particular, utilities were concerned that when behind-the-meter distributed generation was connected to the grid, the variability of energy supply and demand could have significant negative impacts. To help address these concerns and support the ambitious goals of the CSI Program, the California legislature authorized the CPUC to allocate $50 million of the CSI budget to design and implement the CSI Research, Development, Demonstration and Deployment (RD&D) Program (the CSI RD&D Program, or the Program).

In September of 2007, under CPUC Decision 07-09-042, the CPUC launched the CSI RD&D Program with the goal of research, development, demonstration, and deployment to create a "sustainable and self-supporting industry for customer-sited solar in California".[5] The CSI RD&D Program design established three target research areas:

- **Grid Integration: Improving PV integration with transmission and distribution systems (50-65% of funding).**
    - Identify and address key barriers to the development of PV minigrids or central PV.
    - Demonstrate economic viability of new PV system storage technologies.
    - Identify high value locations for distributed generation (DG) PV on transmission and distribution (T&D) and assess the impacts/benefits of large concentrations of DG PV in one location on transmission and distribution.
- **Solar Production Technologies: Supporting commercialization of new PV technologies (10-25% of funding).**
    - Demonstrate economic viability of distributed concentrating PV systems.

[4] California Distributed Generation Statistics. http://californiadgstats.ca.gov

[5] *California Solar Initiative Proposed Research, Development and Demonstration Plan*. California Public Utilities Commission Energy Division. Decision 07-09-042 Appendix A.

    - Support development of integral PV products that become cost competitive with rooftop PV with key technical integration issues addressed (e.g. spacing/cooling).
- **Business Development and Deployment: Supporting the market and end-users (10-20% of funding).**
    - Identify and vet potential roles for utilities in solar PV, including attractive business models;
    - Lower cost, utility grade PV system control, metering, and monitoring capacity;
    - Perform field tests to quantify operational risks and benefits of PV.
    - Demonstrate improved PV economics using advanced metering, price responsive tariffs and storage.

In addition to funding specific research topic areas, the CSI RD&D Program has seven key principles guiding its activities. These are to:

1. Improve the economics of solar technologies by reducing technology costs and increasing system performance;
2. Focus on issues that directly benefit California, and that may not be funded by others;
3. Fill knowledge gaps to enable successful, wide-scale deployment of solar distributed technologies;
4. Overcome significant barriers to technology adoption;
5. Take advantage of California's wealth of data from past, current, and future installations to fulfill the above;
6. Provide bridge funding to help promising solar technologies transition from a pre-commercial state to full commercial viability; and
7. Support efforts to address the integration of distributed solar power into the grid in order to maximize its value to California ratepayers.

In November of 2009, the CSI RD&D Program Manager Itron outlined the details for project solicitations and project selection. Each round of project solicitations followed a consistent process:

- Itron prepared and released a draft Request for Proposal (RFP);
- The final RFP was prepared following a public comment period;
- Public notice of the final RFP was issued by the CPUC; and
- Itron conducted a pre-bid workshop.

Once bids were received, the project selection followed a similar process:

- The proposal scoring team (typically consisting of Itron, the CPUC, the California Energy Commission (CEC), the US Department of Energy, and energy experts) reviewed and evaluated proposals based on project characteristics and selection criteria;
- Itron issued recommendations to the CPUC for funding;
- Itron assisted the CPUC Energy Division with preparing a resolution for Commission consideration; and
- The CPUC approved project funding through the resolution process.

Eligible technologies included solar technologies and other distributed generation technologies that employ (or could employ) solar energy for generation or electricity storage. Preferences for funding were given to in-state businesses or sponsors.

As outlined in the CPUC Decision, project selection was to adhere to the following general guidelines: 60 percent of the projects should see results/target milestones within the first one to three years, 20 percent within four to seven years, and the remaining 20 percent after eight years. The target milestones included using the RD&D funds to help move the market from the current retail solar price of $9/watt to more comparable retail prices for electricity, and to install larger volumes of solar DG that increase the current range of 40+MW per year to 350 MW or more per year.

2.2 Characteristics of Funded Projects

The Program distributed grant funds across five solicitation rounds: two rounds in 2010, one round in 2012, and two rounds in 2014.The following section presents an overview of the projects that were funded through the CSI RD&D Program, including a summary of projects across the five program solicitations and three primary research areas. Table 1 presents the details of each solicitation round.

Table 1: Solicitation Round Characteristics

Solicitation – Resolution Number	Date	# of Proposals	# of Projects Funded	Research Areas	Total CSI Funding Requested	Total CSI Funding Provided
1 - E-4317	Mar 2010	21	8	**Primary:** Grid Integration (GI)	$9,320,472	$7,019,094
2 - E-4354	Sept 2010	95	9	**Primary:** Solar Technologies (ST); Innovative Business Models (BM)	$14,630,058	$12,808,600
3 - E-4470	Mar 2012	32	7	**Primary:** Grid Integration (GI) **Secondary:** Solar Technologies (ST); Innovative Business Models (BM)	$7,624,154	$5,656,325
4 - E-4629	Feb 2014	17	6	**Primary:** Grid Integration (GI)	$6,020,145	$5,104,134
5 - E-4646	Mar 2014	28	7	**Primary:** Grid Integration (GI)	$669,160	$667,766
Total		**193**	**37**		**$38,263,989**	**$31,255,919**

Of 193 proposals, the Program accepted 37 projects across three main research topic areas. Two projects, one in Solicitation 1 and one in Solicitation 3, were cancelled prior to completion. Table 2 provides basic information about each project funded across the five solicitation rounds, including project solicitation, name, primary grantee, project size, and funding characteristics. Projects shaded in gray were cancelled prior to completion.

Table 2: CSI RD&D Project Summary

Solicitation - Project ID	Project Name	Primary Grantee	Research Areas*	Project Status	CSI Funding	Match Funding	Total Funding
1 – 1	Advanced Modeling and Verification for High Penetration PV	CPR	GI	Complete	$976,402	$295,370	$1,271,772
1 – 2	Development and Analysis of a Progressively Smarter Distribution System	UC Irvine	GI	Complete	$297,564	$100,845	$398,409
1 – 3	Planning and Modeling for High-Penetration PV	SunPower	GI	Cancelled	$280,422	$71,643	$352,065
1 – 4	Improving Economics of Solar Power Through Resource Analysis, Forecasting and Dynamic System Modeling	UCSD	GI	Complete	$548,094	$146,254	$694,348
1 – 5	High Penetration PV Initiative	SMUD	GI	Complete	$2,000,089	$1,940,793	$3,940,882
1 – 6	Analysis of High-Penetration PV Into the Distribution Grid in California	NREL	GI	Complete	$991,100	$1,538,727	$2,529,827
1 – 7	Beopt-CA (EX): A Tool for Optimal Integration of EE/DR/ES+PV for California Homes	NREL	GI, CC	Complete	$982,934	$258,653	$1,241,587
1 – 8	Integrated Energy Project Model	KW	GI, CC	Complete	$942,489	$250,000	$1,192,489
2 – 9	PV and Advanced Energy Storage for Demand Reduction	SunPower	ST	Complete	$1,385,286	$747,326	$2,132,612
2 – 10	Improved Cost, Reliability and Grid Integration of High Concentration PV Systems	Amonix	ST	Complete	$1,938,772	$988,365	$2,927,137
2 – 11	Solaria: Proving Performance of the Lowest Cost PV System	Solaria	ST	Complete	$1,092,428	$1,338,013	$2,430,441
2 – 12	Innovative Business Models, Rates and Incentives that Promote Integration of High Penetration PV with Real-Time Management of Customer Sited Distributed Energy Resources	Viridity Energy	BM	Complete	$1,659,999	$840,000	$2,499,999
2 – 13	Low-Cost, Smart-Grid Ready Solar Re-Roof Product Enables Residential Solar Energy Efficiency Results	BIRAenergy	ST, BM, CC	Complete	$1,000,000	$962,557	$1,962,557
2 – 14	West Village Energy Initiative: CSI RD&D Project	UC Davis	ST, BM, CC	Complete	$1,718,004	$1,300,000	$3,018,004

Solicitation - Project ID	Project Name	Primary Grantee	Research Areas*	Project Status	CSI Funding	Match Funding	Total Funding
2 – 15	Advanced Grid-Interactive Distributed PV and Storage	SolarCity	ST, BM	Complete	$1,550,867	$564,742	$2,115,609
2 – 16	Reducing California PV Balance of System Costs by Automating Array Design, Engineering and Component Delivery	SunLink	ST, BM	Complete	$996,271	$1,263,465	$2,259,736
2 – 17	Improved Manufacturing and Innovative Business Models to Accelerate Commercialization in California of Hybrid Concentrating PV/Thermal Tri-Generation Technology	Cogenra	ST, BM	Complete	$1,466,973	$2,200,958	$3,667,931
3 – 18	Quantification of Risk of Unintended Islanding	GE	GI	Complete	$629,100	$1,393,646	$2,022,746
3 – 19	Screening Distribution Feeders: Alternatives to the 15% Rule	EPRI	GI	Complete	$1,669,222	$1,669,343	$3,338,565
3 – 20	Tools Development for Grid Integration of High PV Penetration	DNV GL	GI	Complete	$943,555	$901,345	$1,844,900
3 – 21	Integrating PV into Utility Planning and Operation Tools	CPR	GI	Complete	$852,620	$901,916	$1,754,536
3 – 22	High-Fidelity Solar Forecasting Demonstration for Grid Integration	UCSD	GI	Complete	$1,261,828	$1,353,707	$2,615,535
3 – 23	Solar Energy & Economic Development Fund	SEI	BM	Complete	$300,000	$304,462	$604,462
3 – 24**	Integrating Smart Inverters and Energy Storage into Zero Net Energy Demonstrations	SCE	GI, CC	Cancelled	$0	$0	$0
4 – 25	Standard Communication Interface and Certification Test Program	EPRI	GI, ST	Complete	$882,193	$1,228,919	$2,111,112
4 – 26	PV Integrated Storage - Demonstrating Mutually Beneficial Utility-Customer Business Partnerships	E3	GI, BM	Complete	$717,500	$518,864	$1,236,364
4 – 27	Demonstration of Locally Balanced ZNE Communities Using DR and Storage and Evaluation of Distribution Impacts	EPRI	GI, ST, CC	Complete	$1,484,806	$2,778,825	$4,263,631
4 – 28	Analysis to Inform California Grid Integration Rules	EPRI	GI	Complete	$297,557	$514,398	$811,955

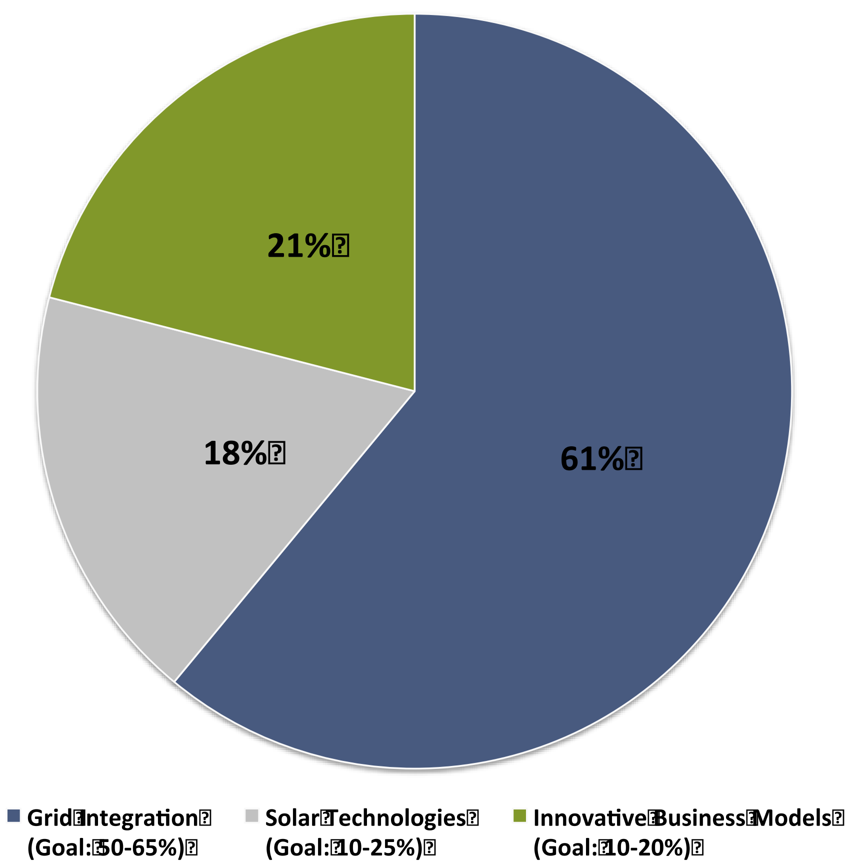
Solicitation - Project ID	Project Name	Primary Grantee	Research Areas*	Project Status	CSI Funding	Match Funding	Total Funding
	for PV						
4 – 29	Advanced Distribution Analytic Services Enabling High Penetration Solar PV	SCE	GI	Complete	$853,556	$1,644,346	$2,497,902
4 – 30	Comprehensive Grid Integration of Solar Power for SDG&E	UCSD	GI	Complete	$868,522	$1,214,850	$2,083,372
5 – 31	Sustainable Energy & Economic Development Fund	SEI	BM	Complete	$100,000	$110,616	$210,616
5 – 32	Monitoring and Evaluation of a ZNE Retrofit Home with Energy Storage, Demand Response and Home EMS	BIRAenergy	BM, CC	Complete	$74,500	$108,788	$183,288
5 – 33	Mitigation of Fast Solar Ramps Through Sky Imager Solar Forecasting and Energy Storage Control	UCSD	GI	Complete	$99,673	$35,000	$134,673
5 – 34	Supervisory Controller for PV and Storage Microgrids	Tri-Technic	GI	Complete	$96,001	$67,040	$163,041
5 – 35	BEopt Multifamily Modeling Capabilities for ZNE and IDSM in California	NREL	CC	Complete	$97,989	$75,596	$173,585
5 – 36	Comprehensive System Assessment of the Smart Grid-tied Energy Storage System Using Second-Life Lithium Batteries	UCSD	ST, CC	Complete	$99,943	$36,917	$136,860
5– 37	Distributed Solar and Plug-In Electric Vehicles (PEV): Development and Delivery of an Interactive Software Platform	CPR	ST, BM, CC	Complete	$99,660	$114,229	$213,889
Total – All Projects					**$31,255,919**	**$29,780,518**	**$61,036,437**

* GI = Grid Integration; ST = Solar Technologies; BM = Innovative Business Models; CC = Cross-cutting
** Project 3-24: Integrating Smart Inverters and Energy Storage into Zero Net Energy Demonstrations was withdrawn before funding was provided. The project originally won a grant for CSI funding of $1,351,907, and had sourced $1,398,460 in match funding.

The CSI RD&D Adopted Plan established guidelines recommending allocation of funding across three RD&D target areas. The Program closely adhered to these recommendations, with actual funding landing close to the recommended allocations, based on the primary research area specified for each project:

- Grid Integration – Recommended allocation: 50-65%; Actual allocation: 61%
- Solar Production Technologies – Recommended allocation: 10-25%; Actual: 14%
- Business Development and Deployment – Recommended allocation: 10-20%; Actual: 24%

Figure 1: Funding by Research Area



In addition to the three research areas, there was a fourth research area classified as 'Cross-cutting Projects'. Cross-cutting projects included projects that covered more than one of the main research areas or involved integration with energy efficiency.[6]

[6] In all but one case, Cross-cutting projects were grouped into one of the other three target areas.

The CSI RD&D Adopted Plan identified cost sharing as an important factor in project selection and a key evaluation criterion. The Program followed the principle that the closer a project is to commercialization, the higher its cost share requirement. In other words, cost share requirements for development projects would be low, while projects reaching the demonstration and deployment phases would be required to provide a 50-75 percent cost share—a target that is fairly consistent with US Department of Energy (DOE) and other funding agency requirements.

Overall, across the three research areas, the Program saw approximately 50 percent cost sharing in aggregate, as shown in Table 3. Cost sharing was lower for Innovative Business Models and Solar Technologies projects and highest for Grid Integration projects, which aligns with the principle outlined above. The lowest project cost share was 20 percent and the highest was 65 percent.

Table 3: Funding and Cost Share Summary

Target Activity	CSI Funding	Match Funding	Total Funding	Cost Share %
Grid Integration	$17,947,659	$19,045,785	$36,993,444	51%
Solar Technologies	$5,883,459	$5,274,662	$11,158,121	47%
Innovative Business Models	$7,424,801	$5,460,071	$12,884,872	42%
Total	**$31,255,919**	**$29,780,518**	**$61,036,437**	**49%**

Additional details on program accomplishments within each of the target areas are presented in separate sections below discussing the evaluation results.

3 Evaluation Methods

3.1 Evaluation Overview

The research and demonstration focus of the CSI RD&D Program makes it fundamentally different from other programs traditionally administered by the CPUC, such as energy efficiency programs, demand response programs, or other self-generation programs such as the Self Generation Incentive Program. These programs typically have a primary goal of achieving direct impacts (e.g., energy savings, energy generation, demand reduction) along with other impacts that can be directly measured in terms of participation counts and equipment installations. Successful RD&D programs, in contrast, are focused on supporting research and demonstration projects that (by definition) are not yet at the stage to produce energy savings. Other factors that differentiate research programs from energy efficiency programs include:

- Longer timelines associated with research projects, relative to traditional efficiency programs;
- Program impacts that may be several times removed from the initial program activities;
- Research projects that fail are not necessarily indicators of an unsuccessful program; and
- Knowledge benefits and network effects (two key outputs from any successful RD&D program) are primary research program outputs and can be difficult to quantify.

Traditional energy efficiency program evaluations focus on energy savings and other market results that can be quantified using well-established analysis methods. If these traditional evaluation methods are applied to RD&D programs, however, many of the most important program benefits will be missed, as they do not manifest themselves as direct market outputs.

To guard against this, the CSI RD&D Program evaluation used analysis methods tailored specifically to capture all the potential benefits of an RD&D program. This theory-based evaluation design focusing on the underlying program logic was designed to incorporate all of the complex interrelations between program actors and external knowledge recipients. The evaluation was also designed to be consistent with two important guidance documents on evaluating RD&D programs: the California Emerging Technologies and

Market Effects Evaluation Protocols and the DOE/EERE Standard Impact Evaluation Method.[7]

As discussed previously, CPUC Decision 07-09-042 identified the following key criteria for the CSI RD&D Program, which were addressed in this evaluation:

- The sizes of the grants obtained from CSI RD&D funds;
- The benefits for California ratepayers;
- The economic value to the California grid;
- Whether and how the project expanded photovoltaic (PV) market opportunities or reduced barriers;
- Leverage from other funding sources (use of match funds);
- Institutional and regulatory acceptance of project findings or outcomes (technology transfer and follow-on use); and
- Clean jobs created through CSI RD&D funding.

The evaluation took place in 2016 at the same time as the final projects in the Program were being completed; the last project was completed in December of 2016. Given this, there were limitations to what the evaluation could identify due to the fact that 16 of the 35 CSI RD&D projects were yet to be completed at the time this evaluation started. The effects of many of these projects may not be evident for years into the future. Based in part on this challenge, the evaluation team conducted a structured, qualitative assessment of program effects. This assessment provides a sufficiently well documented preponderance of evidence from which to draw conclusions about the effect from the CSI RD&D Program on the California solar market.

Each of the major evaluation methods is described below.

3.2 Evaluation Methods

3.2.1 Program Logic Model and Progress Metric Development

The foundation of a theory-based evaluation is the development of a program logic model. This is critically important when evaluating an RD&D program, as program effects are more complex and can be missed entirely if not identified as part of the logic model that covers a timeframe and agency landscape that is appropriate for a research program. Details on the logic model are provided in Section 4 of this report.

[7] The two documents can be found at: http://www.calmac.org/publications/EvaluatorsProtocols_Final_AdoptedviaRuling_06-19-2006.pdf and http://www1.eere.energy.gov/analysis/pdfs/evaluating_realized_rd_mpacts_9-22-14.pdf.

The primary use of the logic model is to guide the measurement of program effects. At a high level, the logic model describes the activities and immediate outputs of the Program, as well as the expected outcomes of the Program activities and the pathways through which these will be achieved over time. The evaluation team used the logic model as a guide to define specific metrics to measure progress along the path from inputs to activities and then to outputs and outcomes. The evaluation team reviewed program and project documents, and held discussions with program management staff to develop program theory and construct the Program logic model.

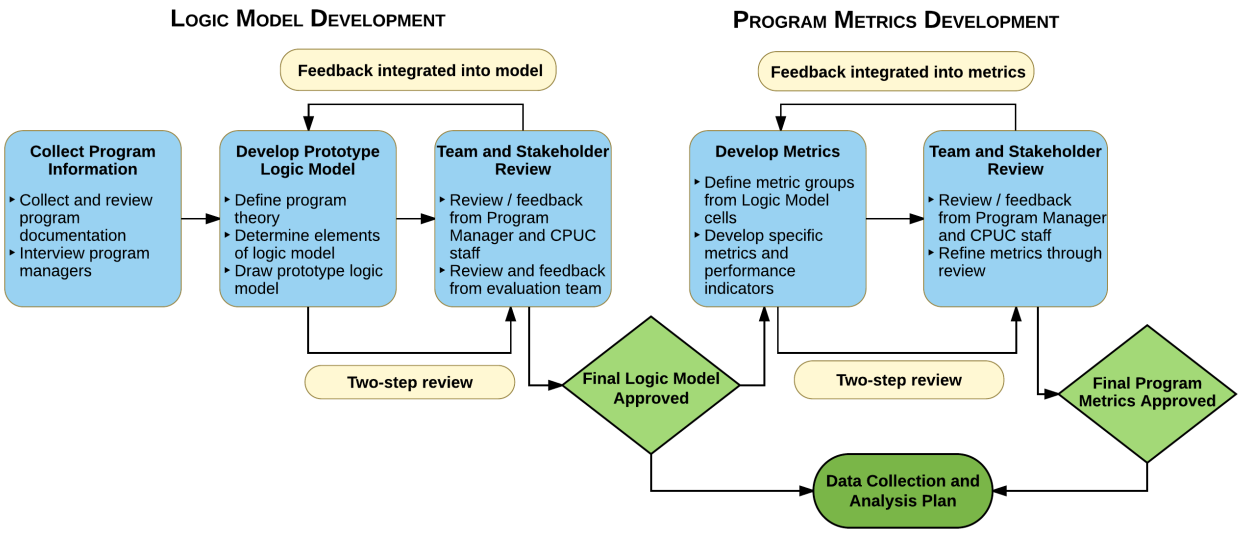
The resulting logic model uses the goals and principles of the Program as ultimate outcomes and shows pathways to these outcomes in four areas:

1. Additions to the *Knowledge Base*
2. Facilitation of *Grid Integration* through Models, Tools, and the Development of Governing Standards
3. Acceleration of New *Solar Technologies*
4. Development of *Innovative Business Models*

Once the logic model was approved, the evaluation team constructed a specific set of metrics to indicate progress along pathways to each outcome in each of the four areas listed above. These metrics were again reviewed, and program management staff and CPUC staff provided feedback and approval for the metrics. Once the metrics were approved, the evaluation team designed a data collection plan that was structured around the logic model and resulting metrics. Each metric was carefully reviewed and linked to specific data collection and analysis activities. In this way, all metrics were covered by data collection activities, and all data collection and analysis activities were explicitly linked to underlying elements of the program logic model.

Figure 2 summarizes the logic model development process and how it was used to develop program metrics addressed by the evaluation. Additional detail on the specific program metrics identified is provided in Appendix A.

Figure 2: Logic Model and Program Metrics Development Process



3.2.2 Data Collection

Once metrics were identified that would provide evidence of the Program's progress toward its goals, the evaluation team developed a data collection plan to gather information on these metrics from a variety of different sources. Primary data collection activities included:

- ***Compiling Program and project data and documentation*** – Collecting all relevant program decision and design documents, and all project-related data that were tracked for each project, including project proposals, progress reports, financial information, final project reports, and publications.
- ***In-depth interviews with grantees and program managers*** – Obtaining additional information on the projects not included in the project data, such as perceptions of program delivery, information about project execution, and opinions about the actual or predicted effect of projects.
- ***In-depth interviews with industry experts and stakeholders*** – Collecting information on how program outputs, knowledge, and expertise from the Program projects are affecting the broader solar community, grid operators, utilities, and regulators.
- ***In-depth interviews with market actors*** – Collecting information on how project outputs, knowledge, and expertise from the Program projects is affecting the broader solar market.
- ***Survey of market actors*** – Fielding an online survey to a broad variety of market actors to collect standardized quantitative data to measure the short-term outcomes of the Program.

- *External data/literature* – Collecting secondary data and literature to investigate knowledge dissemination of the Program-supported research including bibliometric and patent data to assess the reach of projects.

The evaluation team worked with the CPUC and the Itron program management staff to develop detailed interview guides for each of the in-depth interview target groups. Each interview guide was carefully designed in support of the data needs required to estimate outcome metrics in each research area.

The market actor survey was designed to measure short-term outcomes of the Program related to increasing the knowledge base of the California solar market beyond the funded projects including project awareness, new skills, acceptance, follow-on use, filling of capacity gaps, and integration of project outputs in the market. The survey targeted specific segments of the California solar market that we expected, based on evidence in the program documents, to have had early exposure to the Program or its outputs.

Table 4 presents a disposition of the interview activities and survey sample frame.

Table 4: Interview and Survey Activity Disposition

Data Collection Activity	Description	# Interviews / Surveys Planned	# Interviews / Surveys Completed
In-Depth Interviews			
Program manager/ grantee interviews	Includes interviews with CSI Program Manager, project grantees and sub-grantees	50	48
Stakeholder interviews	Includes interviews with utility staff, solar program managers, ISO staff, regulators, solar industry organization staff such as CalSEIA, CalSEPA	5-10	12
Technology expert interviews	Interviews with solar experts such as staff from national labs or research institutes	5-10	3
Market actor interviews	Interviews with market actors potentially affected by the Program such as installers, manufacturers, balance of system companies, builders, etc.	5-10	5
Total In-Depth Interviews			**68**

Market Actor Survey		Sample Size	Completes
	Individuals on the CalSolar listserv	888	57

	Individuals from teams that submitted losing proposals to the program	154	11
	Attendees of the DOE-CSI joint forums	142	17
	Individuals cited in project patent applications technical reports	105	3
Total Survey Participants		**1,289**	**88**

The Evergreen team compiled the outputs of the data collection efforts and imported them into Dedoose, a qualitative analysis software platform. The Dedoose software facilitated efficient analysis of large amounts of qualitative data, allowing the evaluation team to organize data sources based on relevant characteristics, segment and categorize data according to themes, search for and retrieve information across themes, and identify significant patterns in the data.

Table 5 provides an account of the data sources the evaluation team entered in Dedoose for analysis.

Table 5: Data Source Count

Data Source	Count
In-Depth Interviews	68
Project Final Reports	35
Project Webinars	53
Project Proposal	37
Progress Reports	64
Total Documents	**257**

Once the data were compiled into Dedoose, the evaluation team developed a comprehensive coding scheme for use by all interviewers and analysts. This qualitative coding scheme consisted of a nested set of codes or code "tree" which was used to label information in data sources according to themes or ideas. In this case, codes were directly aligned with program metrics from the logic model, along with the network analysis goals.

Due to the quantitative nature of the market actor survey, the evaluation team compiled the results of the survey separately. The survey responses were imported to SPSS, and results were tabulated and analyzed.

The resulting Dedoose and SPSS datasets provided the foundation for the main evaluation analysis tasks detailed below.

3.2.3 Network Analysis

The goal of network analysis was to evaluate the knowledge benefits that have accrued to the state of California, the solar community, and the energy industry from Program activities. The evaluation team developed a network analysis methodology that was designed to measure the following:

1. Cumulative knowledge benefits produced by the Program;
2. Trajectory of knowledge diffusion based on the fit of knowledge produced relative to the intended audience;
3. Means by which knowledge is transferred to market actors; and
4. Existing knowledge capacity that the Program drew on, and the extent to which the Program built additional knowledge capacity.

We utilized the hybrid name generator as the most appropriate network analysis method for this evaluation,[8] which involved a structured interview section where grantees and sub grantees were prompted if they interacted with actors from each of the following categories:

- Utilities or Independent System Operators (ISOs)
- Standards and testing organizations
- Research organizations, including national laboratories
- Solar hardware or installation firms
- Trade associations or non-profits

The results from this portion of the interview results were supplemented with data from several other sources, including:

- Market actor survey
- Other organizations mentioned by interviewees
- Team compositions from program documents (proposals and progress reports)
- Interactions with specific outside actors noted in program administrator progress reports

[8] Henry, A. D., Lubell, M. and McCoy, M. (2012), "Survey-Based Measurement of Public Management and Policy Networks". *J. Pol. Anal. Manage.*, 31: 432–452.

This process generated the data needed to characterize the network and determine its size. The results of the network analysis are described in more detail in Section 9 on knowledge benefits, with an expanded discussion included as Appendix F.

3.2.4 Citation Analysis

Another measure of the Program knowledge benefits and the reach of Program knowledge is the level of dissemination of project reports and publications. To this end, the evaluation team analyzed the citation of project reports and academic papers. We collected bibliographic and intellectual property data for the CSI RD&D projects through the services of Thompson Reuters, which was supplemented by using a web-scraping tool to search Google Scholar, as some projects may have resulted in Internet publications not found among the standard academic literature. Using these data, the evaluation team examined the following:

- Number of citations per project reports and paper
- The venue where a Program source was cited
- The organization type of the citing author's affiliation
- The citation pattern over time

The results of the citation analysis are also included in Section 9 in the discussion of knowledge benefits produced by the Program.

3.2.5 Delphi Panel

The final task completed by the evaluation team was to convene a Delphi panel to review the research findings and conclusions regarding the effects of the Program. The Delphi panel consisted of four experts with experience in either RD&D program evaluation or the solar industry itself. The Delphi panel was sent a summary of the research findings in the areas of Grid Integration, Solar Technologies and Innovative Business Models. Based on the summary findings in each of these areas, the Delphi panelists were asked to provide an assessment via numerical rating as to the likelihood that the projects in these areas would help meet the original CPUC goals established for the CSI RD&D Program. Following the initial assessment, the Delphi panel met via conference call to discuss the individual ratings. The panel members were then given an opportunity to revise their initial ratings based on the results of the conference call.

The Delphi results are discussed where appropriate with the evaluation conclusions, and the materials included in the Delphi panel review packets along with the final ratings are included as Appendix I.

4 Logic Model and Performance Metrics

The first step in conducting a theory-based evaluation is to develop a comprehensive program logic model that clearly illuminates the theoretical links between program activities, outputs and various downstream outcomes. As discussed in the previous section, this is especially important for an RD&D program, where program impacts can be less visible compared to more traditional energy efficiency programs.

At the start of the evaluation, the evaluation team reviewed program documents and had several meetings with Itron program staff to develop a program logic model for the CSI RD&D Program. The objective of this CSI RD&D logic model is to guide the evaluation of program impacts. At a high level, the logic model describes the expected outcomes of the program and the pathways through which they will be achieved. The evaluation team used the logic model to identify specific metrics to be measured along the path from inputs to activities and then outputs and outcomes.

As discussed previously, the ultimate goal of the CSI RD&D Program is to facilitate acceleration and expansion of grid connected solar energy resources while also providing value to California ratepayers. The Program accomplishes this by increasing the visibility and reliability of solar output, improving grid management and interconnection tools, and developing innovative supporting technologies and processes.

The logic model uses the goals and principles of the program as ultimate outcomes and shows ***pathways to these outcomes*** in four areas:[9]

- **Additions to the *Knowledge Base***. Improving the *Knowledge Base* was common to all of the RD&D projects and underlies the specific accomplishments of the other three pathways. The *Knowledge Base* is reflected in both written records and professional experience and is expressed through professional relationships, their skills, and perceptions. Related activities include building a technical body of knowledge, as well as improving R&D methodologies, networks and methods to disseminate, transfer, and exchange knowledge, and the ability to leverage past R&D experiences.
- **Facilitation of *Grid Integration* through Models, Tools, and the Development of Governing Standards.** The *Grid Integration* efforts include technical advances in modeling and tools (mostly for use in planning and management of solar T&D), as well as technical support and data useful in developing standards and guidelines for the deployment and management of solar resources. These activities contribute to improved usability, reliability, and cost-effectiveness of solar output. They also provide greater flexibility and functionality in grid integration, creating greater ease

[9] The individual grantee projects usually contributed to more than one of these areas.

for utilities, system operators, and others to implement new solar projects and manage high penetration levels of solar resources.

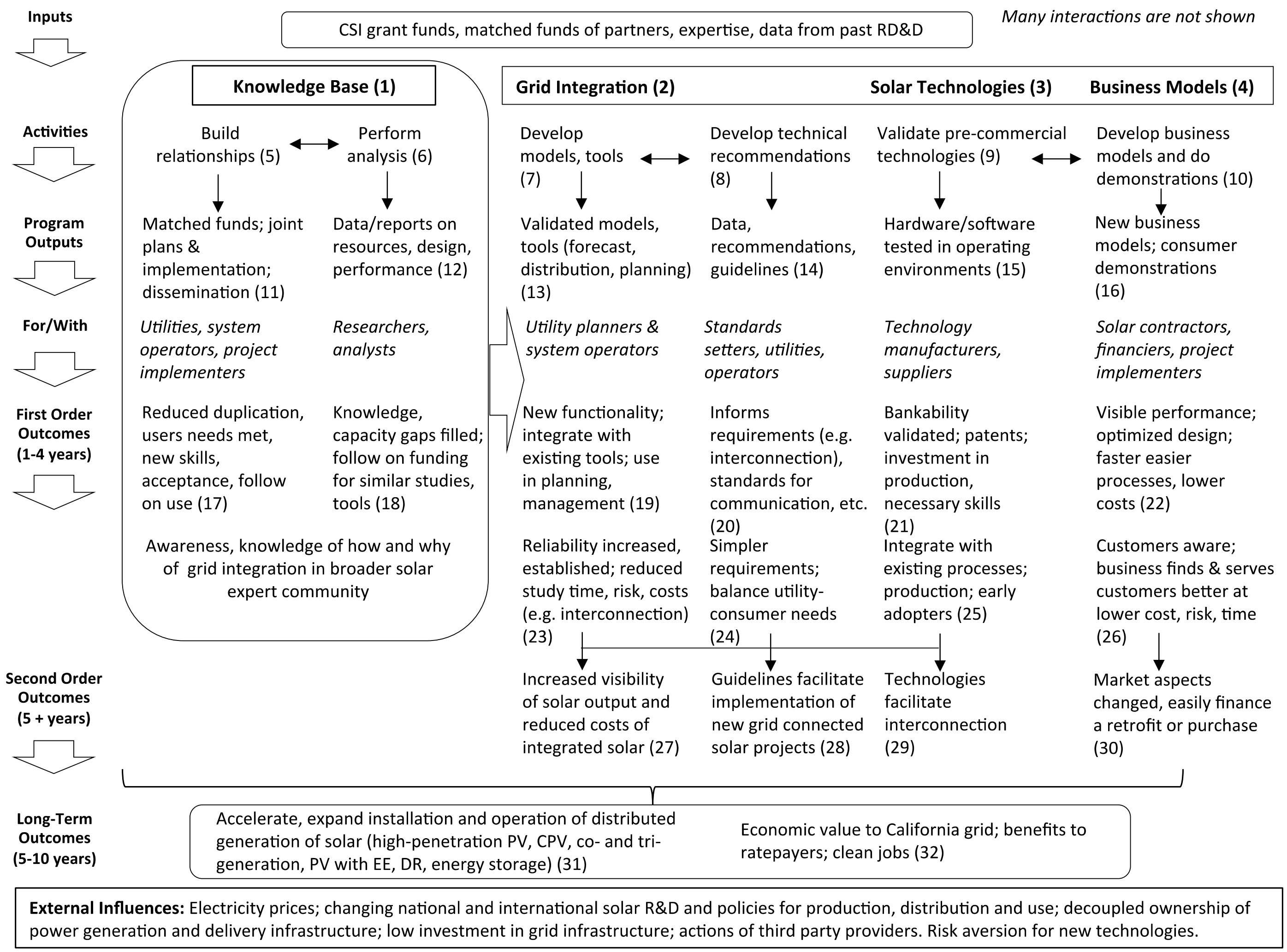
- **Acceleration of New *Solar Technologies***. The *Solar Technologies* activities focused on validating pre-commercial hardware and software designed to improve or enhance the performance, reliability and/or cost-effectiveness of solar systems and components.
- **Developing *Innovative Business Models***. The *Innovative Business Models* development effort is a smaller part of the RD&D scope in terms of budget, but combines two areas of emphasis: the development of new models for how solar business can be successfully accomplished, and performing demonstrations of new technologies or processes. The demonstration projects enhance customer acceptance and also exhibit economic benefits and potential for investors and solar companies. These can lower balance of system costs and convince market actors of the feasibility of adopting solar technology.

Figure 3 presents the CSI RD&D Program logic model covering these four pathways. Numeric labels in the figure provide a key to map the logic model components to metrics and data collection activities provided later in the following section. The development of this particular categorical structure of program activities and pathways is driven primarily by the nature of the differences in the expected outcomes for each.

For each of the core program activity areas (labeled as logic model elements #1-4), there are a series of program *Activities* that result in direct program *Outputs*. From these outputs, the program logic prescribes a series of *Outcomes* that are assumed to occur if the program is functioning properly. These *Outcomes* are defined by expected time frame, either short-term *First Order Outcomes* (1-4 years), mid-term *Second Order Outcomes* (5+ years), or *Long-term Outcomes* (5-10 years). Given the timing of this evaluation, most of the evaluation measurement will focus on the *First Order Outcomes*, as not enough time has elapsed to expect much progress for the longer-term effects.

The *"For/With"* row in the logic model is there to clarify who partners are and who are the direct users of the outputs, as these are the groups that will either help create or benefit from the desired outcomes. Finally, *External Influences* refers to contextual factors that shape the circumstances and landscape within which the program operates and the primary factors that can speed or hinder the appearance of the desired outcomes.

Figure 3: California Solar Initiative RD&D Logic Model



The final logic model was used to create a comprehensive data collection plan for the evaluation that systematically linked metrics of progress from the logic model to specific research questions. The data collection plan is structured in accordance with the four primary activity areas shown in the logic model: *Knowledge Base*, *Grid Integration*, *Solar Technologies*, and Innovative *Business Models*. Each activity area has a unique set of expected outputs and outcomes, as depicted in the logic model. Once the individual research questions were articulated, data sources were assigned to ensure that all of the important issues were addressed by the evaluation. The detailed data collection plan linking metrics, research questions, and data sources is included as Appendix A of this report.

In the data collection plan, the format for each of the data collection activities is the same. For each of the four program activities, each related program output and outcome is included in a table along with the corresponding number from the logic model diagram in Figure 3. For each output and outcome, specific metrics are provided that—when measured—can provide an indication of whether the underlying program logic is succeeding in practice. Each metric is then linked to specific data collection and analysis activities. In this way, all metrics are covered by data collection activities, and all data collection and analysis activities are explicitly linked to underlying elements of the program logic model.

As discussed in Section 3, the data collection activities consisted of the following methods:

- ***Grantee data (D)*** includes all project-related data that is tracked for each grantee. This includes items such as project descriptions, project budgets, original proposals, performance data, reports/publications, and progress reports.
- ***In-depth Interviews w/ grantees (IDI-G)*** refers to in-depth interviews with grantee project managers to obtain additional information on the projects that is not included in the project data (e.g., what worked, what did not, perceptions of the funding process, recommendations for improvement).
- ***In-depth Interviews w/ industry experts and stakeholders (IDI-E)*** collected information on how well information from the grantee projects is affecting the broader solar community.
- ***In-depth Interviews w/ market actors (IDI-MA)*** were done to collect information on how well information from the grantee projects is affecting the broader solar community (in addition to the interviews with industry experts and stakeholders).
- ***Survey of Market Actors (Su-MA)*** is an additional online survey fielded to market actors to collect more standardized information (e.g., data that are more numeric that are less in need of a less structured in-depth interview).

- ***External data/literature (S)*** includes secondary data and literature that reflect knowledge dissemination of the Program-supported research.

The following sections provide the evaluation assessment of the progress made by the Program in each of the four activity areas, based on these data collection activities. A separate section is also included discussing the overall management of the CSI RD&D Program.

5 Overall Program Administration

Part of the evaluation was devoted to collecting feedback on how the CSI RD&D Program was implemented by Itron, the CSI RD&D Program Manager. Evergreen Economics completed interviews with either the primary investigator or a project partner for 34 of the 35 completed projects. In addition to asking questions about their specific project goals, outcomes, and effect on the solar market, we asked about their experiences with the CSI RD&D Program and their interactions with Itron. Specific topics included:

- How grantees first became aware of the CSI RD&D Program;
- Grantee experiences with the solicitation process;
- Grantee experiences with the project award and contracting processes;
- Overall perceptions/feedback from interacting with Itron during the course of the project;
- Specific challenges in the project administration; and
- Suggestions for improving the design of future RD&D programs.

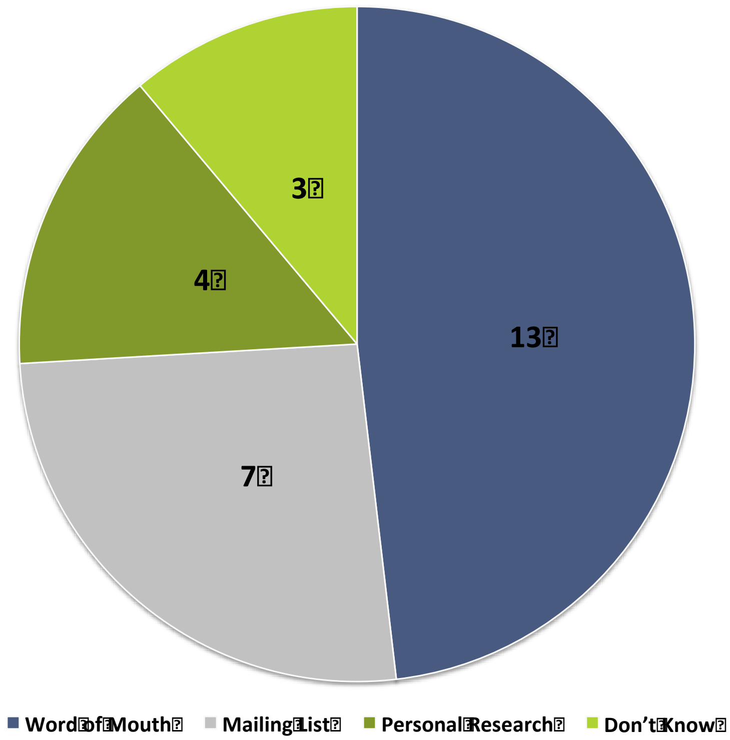
The evaluation findings relating to the CSI RD&D Program management are discussed below.

5.1 Program Awareness

In order to understand how grantees learned of the CSI RD&D funding opportunity, we asked how they first became aware of the CSI RD&D Program. Figure 4 presents the number of grantees that learned of the CSI RD&D Program across three primary methods.[10]

[10] Note that the total does not equal 34 because there were some grantees with multiple projects.

Figure 4: Count of Grantees by Method of Awareness of Program



As the figure illustrates, most of the interview awardees became aware of the CSI RD&D funding opportunities by word of mouth (13), either through conferences, past RD&D projects, project partners, or colleagues. Seven grantees stated that they first heard of funding opportunities through mailing lists (email lists, RFPs, and list serves), four noted they keep track on their own by visiting websites such as CalSolarResearch.com and PEER looking for solicitations and grant funding opportunities, and three were unable to recall where they had heard about the funding opportunity.

5.2 Experience with Solicitation and Contracting Phases

Overall, grantees were very satisfied with the solicitation phase of the CSI RD&D Program and did not have any major concerns about the program design and delivery, with many noting that it was "very straightforward" and the process was completed in a timely manner. One respondent noted that, "Overall it was a really good experience," and added "the solicitation design was flexible and targeted the research concepts well." In general, grantees did not have many difficulties meeting the requirements for solicitation applications and felt the instructions were easy to understand, and communication about the applications was clear and timely.

Once the projects were approved, they moved into the contracting and development phase. While all grantees noted that the contracting process was well managed, nine grantees expressed some level of frustration or challenge with the contracting phase, noting it as at times tedious and difficult to navigate. In general, the challenges in contracting revolved around contract wording around intellectual property rights and cost ratios. Across the nine grantees that experienced challenges, all were resolved and all projects ended up moving forward.

5.3 Experience with Program Management

The vast majority of the grantees interviewed mentioned Itron as a key source of program information, and all grantees expressed a very high level of satisfaction with the Itron program management. Key reasons given for the high level of satisfaction included that the Itron was flexible and willing to help guide any part of the solicitation and program processes, the Itron project managers were experts not just at the program management level but also in the subject matter of the projects, they had good connections to other stakeholders, and they frequently acted as conduits to facilitate networking opportunities or pass on knowledge.

One grantee stated that:

> *"From my standpoint, this was the best program that I had been involved in. It was the most realistic, at least the way it was worded for us in terms of expectation and deliverables"*, another stated that *"I manage a lot of research projects and if I could pick one entity I would like to work with again, it would be this one. I am doing projects with EPIC, Sunshot, and NREL, and this one is right on. I want to add, you know the reason I liked it was not because they were easy on me. There was a case, for example, where my team pushed back on a request from Itron concluding it was more difficult than anticipated. So I went and asked Itron about changing the scope and they came back and said no, sorry you signed up for this and if you don't want to do this that's okay, but we won't release funding. I felt like we were able to apply the dollars that were received to figure out the technical goal of the project opposed to burning it on paperwork or keeping people informed. It was the right level of oversight*".

Finally, another grantee with significant research experience noted that:

> *"I think actually it was the best experience I have had in my life with grant management"*.

Overall, communications and coordination among Itron staff and its contractors were generally described as excellent, with regular meetings, frequent phone calls, and the ability to provide expert opinions in the research areas.

One respondent noted that:

> *"They kept overhead low and came up with special and good ideas about how to disseminate ideas that worked very well."* They added, *"I think it has been a very successful project and I think they should do it again."*

5.4 Program Challenges and Possible Suggestions for Improvement

While overall, the feedback received on the Program and Itron's management was very positive, there were some challenges and recommendations for improvement. Grantees described the following challenges about the CSI RD&D Program:

- The time period between submitting a proposal to receiving an award and beginning the work was too long; technologies and requirements change rapidly causing the scope of work to change.
- One interviewee believed that the final results were not visible enough to the public, noting that they were concerned with how the "CSI website buries the reports" and how they are not easily accessible.
- Almost universally, interviewees thought that the reporting stage of the project was cumbersome and difficult to coordinate.
- Multiple interviewees noted that the invoicing process was tedious and confusing, particularly when multiple project partners were involved.

Grantees also had the following suggestions to improve the CSI RD&D Program:

- Provide a template for the final report much earlier on in the research process.
- Introduce meetings between contractors and the CPUC in order to engage them more in the end result.
- Provide more stakeholder involvement and make some draft reports public to receive more feedback.
- Ensure that the final documents and other program documentation are publicly available, easily accessible, and well publicized.

6 Grid Integration

6.1 Grid Integration Project Accomplishments

An important area of emphasis for the CSI RD&D Program was the facilitation of solar grid integration, particularly for solar power coming from distributed consumer-based sources. Grid integration efforts are distinct from more traditional RD&D efforts focused on progress of distributed energy technologies and controls systems, and instead are focused on ensuring that these resources can be safely and efficiently tied into the existing or future electricity grids, as well as integrating solar with other resources such as energy efficiency and demand response.

The *Grid Integration* projects were very successful, with the majority (19 of 20) of projects meeting all their original objectives and having findings widely disseminated to their target audiences.

At the outset of the CSI Program in 2006, the California energy grid was looking at a future with high penetration levels of PV due to aggressive goals for renewable energy resource integration including solar PV. A major challenge facing these efforts was that the industry and utilities in particular lacked understanding and familiarity with how PV systems might impact grid operations at high penetration levels. The likelihood of sustaining high PV growth rates in some part relied on the ability, and willingness, of utilities to integrate PV systems into the electric grid, and in a way that provided benefits to both utilities and utility customers. The CPUC identified Grid Integration as a key focus area for the CSI RD&D Program that was not being served by other R&D efforts, and where the CSI RD&D Program could provide high value for grant funds.

In total, there were 20 Grid Integration projects, which are summarized earlier in Table 2:. These projects are also referred to by number in some of the subsequent tables. Prior to soliciting bids for Grid Integration projects, the CPUC identified key areas of grid integration needs and knowledge gaps, which are summarized in Table 6.

Table 6: Grid Integration Needs and Knowledge Gaps

Area of Need	Description
Planning and modeling for high-penetration PV	Utility grid operation models and planning tools lacked the capability of identifying and optimally siting and incorporating distributed generation technologies and resources. In addition methods for estimating solar resources and forecasting PV system output at high penetration levels were limited and relied on low-resolution insolation data.
Testing and development of hardware and software for high-penetration PV	Existing distribution circuits are generally capable of tolerating some variability in load, however high penetration PV introduces significantly greater variability due to geographic dispersion, impact of variable environmental factors such as intermittent cloud cover, and the fact that behind the meter generation is often invisible to behind-the-meter generation resources. These factors introduce significant challenges to grid integration and overall grid reliability. This situation requires enhanced data, improved analytical capabilities, and development of robust hardware and software resources, including protocols and formal standards, capable of dynamic interaction and communication with the grid to control, and mitigate against issues arising from, varying frequency and voltage conditions on the grid.
Addressing integration of energy efficiency, demand response and energy storage with PV	Significant opportunities exist for integration of distributed PV resources, energy storage, demand response and energy efficiency measures. Improved energy storage and controls could potentially transform distributed generation resources into reserve resources, and allow customers to avoid energy price volatility and respond to demand response events. Energy efficiency measures help reduce the energy footprint of a site and when installed with PV systems can help reduce the size and capital costs for PV systems. Lack of integration means these opportunities are often missed. This presents a need to integrate energy efficiency, demand response, energy storage and PV systems through improved efforts like guidelines on appropriate energy efficiency measures to with PV system integration, combined audits, and improved battery storage and control systems.
Demonstration Projects for Utility Interconnection and Grid Operations Tools, Technology, and Methods	Solicitations 3, 4 and 5 identified the need to move toward demonstration and operationalization of outputs. The specific areas of need included demonstrations of: PV project screening methods for interconnection, development of technology and protocols for advanced inverter technology, processes for streamlining interconnection and offsetting system upgrade costs, investigations of common challenges to interconnection and mitigation strategies to support standards and rulemaking working groups, methods for optimal siting of PV to enhance value to the grid, methods for risk quantification, enhanced distribution system modeling with capabilities for identifying risks such as islanding, methods to identify distribution line loading and congestion, interconnection of inverters with smart meters, tools with capability for utility system control and inverter dispatch, field tests of high penetration PV, and energy storage systems with capability to provide response to dynamic loads at distribution feeders.

Area of Need	Description
Demonstration of Enhanced Solar Modeling	Solar resource models with higher spatial and temporal resolution to enable better forecasting and planning by grid operators and the CAISO. Validation of estimated PV production at high temporal resolution (less than one-minute intervals) using metered PV data. Of particular interest are demonstrations where PV performance data is collected from Smart Meter/inverter applications that can be used to validate high temporal resolution PV output estimates for anticipated high PV penetration situations.

A mapping of how the 20 funded Grid Integration projects relate to the knowledge gaps and needs areas is provided in Table 7.

Table 7: Knowledge Gaps and Areas of Need Addressed by Projects

Area of Need	Project ID	Key Project Activity Examples
Planning and modeling for high-penetration PV	1, 2, 4, 5, 6, 18, 19, 21, 22, 26	• Enhancement of insolation data • Enhancement of PV system modeling methodologies and tools • Verification of modeling methods and tools against field data • Development of screening methodology to evaluate new interconnection requests • Methods to estimate impacts from high penetration PV • Modeling impact of ZNE homes • Analysis methods to inform grid integration rules and standards
Testing and development of hardware and software for high-penetration PV	1, 5, 6, 18, 20, 25, 26, 28, 29, 33, 24	• Development of software visualization tools • Enhancement of utility software tools to incorporate enhanced simulation and forecasting methodologies • Lab and field testing of advanced PV inverter technology • Testing ability of inverters to detect and react to islanding conditions • Assessing potential for open standard communication interfaces for smart inverter technology • Developing standards and protocols for hardware
Addressing integration of energy efficiency, demand response and energy storage with PV	7, 8, 27	• Enhancement of existing building modeling software to incorporate identification and implementation of balanced, optimal, and cost-effective integration of EE, DR and PV • Development of data transfer formats for information exchange between software platforms for integrated energy projects

Area of Need	Project ID	Key Project Activity Examples
		• Demonstration of cost effective strategies for ZNE homes incorporating PV
Demonstration projects for utility interconnection and grid operations tools, technology, and methods	5, 18, 19, 20, 25, 26, 27, 28, 29, 33, 34	• Deployment and testing of solar irradiance and cloud speed sensors • Demonstration and quantification of value of PV integrated storage • Demonstration of system control software for micro-grids
Demonstration of enhanced solar modeling tools	5, 21, 22, 26, 27, 29	• Field validation of PV simulation and forecasting model methods and software • Integration of PV fleet simulation methodologies into utility software tools • Development of end-to-end modeling software integrating building modeling and energy storage into distribution modeling.

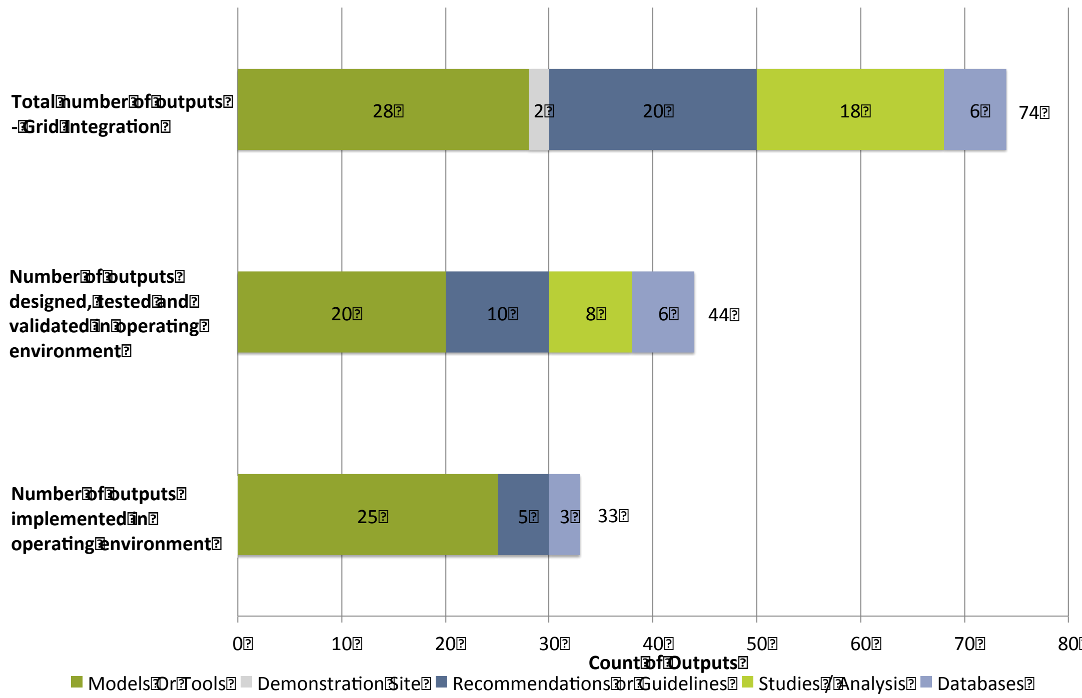
Figure 5 summarizes the Grid Integration project activities that generated 74 discrete 'outputs' relating to the logic model.[11] Examples of these outputs include:

- Databases
- Solar Project Screening Methodologies
- Modeling Tools or Algorithms
- Technical Protocols
- Field Demonstration Sites
- Grid Planning and Management Software
- Studies and Analysis

Of these 74 outputs, 44 were tested and validated in an operating environment, with 33 having documented adoption by the industry in at least one application. As discussed in the next section, the Grid Integration project results have seen a relatively high level of use within California, with project outputs being utilized by the IOUs and other utilities, the California Independent System Operator (CAISO), and standards and rulemaking organizations.

[11] See Appendix A: Data Collection Plan for a complete listing of all the logic model outputs that were considered in the evaluation for the Grid Integration projects.

Figure 5: Grid Integration Outputs (Logic Model Cell 14, 19)



6.2 Assessment of Grid Integration Project Accomplishments Relative to the Logic Model Progress Metrics

Based on the nature of the Grid Integration projects and observed project accomplishments, we identified specific areas within the logic model for assessing the impacts of these projects relative to the milestones needed for program success.

In the discussions below, the assessments of program progress were informed through several data collection activities, primarily:

- Program documentation review - including program design documents, project proposals, progress reports, final project reports, publications, and project data.
- In-depth Interviews with grantees and program managers – including primary grantees and sub-grantees. At least one project team member for each project was interviewed, except for Project 17.
- In-depth Interviews with industry experts and stakeholders – stakeholder group included representatives from organizations related to but not always directly involved in Program projects including utilities staff, solar program managers, industry organizations such as CalSEIA, regulatory agencies, and the CAISO. The expert group was comprised of industry experts from academia, public laboratory

researchers, state employees, and private sector researchers. These individuals were selected from the following sources:

  - Individuals named as stakeholders on specific projects
  - Individuals who took part in stakeholder advisory groups
  - Attendees of joint DOE-CPUC High Penetration Solar Forums in 2011 and 2013
  - Authors of literature cited in project reports

- In-depth Interviews and a survey with market actors – individuals from market facing organizations such as manufacturers, software developers, standards setting organizations and others, involved with or knowledgeable of program projects.

Our expectation during the interviews was that grantees would have strong project-level knowledge and some program-level knowledge from the other projects they were exposed to. Similarly, stakeholders would have some specific project knowledge while others would have broader program level knowledge. Solar industry experts would have broader opinions of the effects of project outputs on the wider solar market and on solar research. This turned out to typically be the case; however, there were some members of the solar expert group that had limited exposure to the Program. All respondents were provided with website details for the CSI RD&D Program where they could access project documentation prior to the interview. However, they were not explicitly instructed to review these materials. Each respondent group was asked questions across the following topics, but each was tailored specifically to the respondent group:

- Their level of engagement with the CSI RD&D Program;
- How the Program facilitated, and the effect of, networks and relationship building;
- The market relevance of projects and where project teams gathered information and how they exchanged knowledge and know-how; and
- The effect or influence of projects and outputs across the research areas, and how projects filled gaps and addressed challenges faced by the solar market.

6.2.1 Grid Integration Short-Term Outcomes

The key short-term metrics of program progress identified in the logic model are summarized in Table 8, along with the evaluation team's assessment of progress in these areas. For the short-term outcomes, the Grid Integration projects made solid progress in achieving the first stage accomplishments dictated by the program logic. These first order outcomes are accomplishments that are expected in the 0-4 year time frame and are necessary first steps toward achieving the longer-term program goals.

Table 8: Grid Integration Short-Term Outcomes – Metrics and Progress Assessment

Key Logic Model Metric	Progress Assessment
Short-Term Outcomes (0-4 years)	
Standards or rules influenced	High
Impact of recommendations on inverter system communication protocols	High
Improvement in system reliability brought by new models, tools	High
Reduced cost, saved time and lowered risk of new projects and system operations	High
Evidence of simpler/streamlined interconnection requirements	Medium
Lower transaction costs for implementing solar projects	High

Additional detail and discussion on each of these short-term metrics is included in Appendix C.

Standards and/or rules influenced

Common standards and rules provide broad benefits to any industry, ensuring the safety and quality of products and services, making product development and production more streamlined, making it easier for businesses to develop new products and access new markets, improving efficiency and reducing costs for manufacturers, and providing assurance for consumers that products and systems are safe and reliable. Targeting the development or improvement of standards is one way to have a high effect on a market; however, this requires identifying and engaging specific individuals or organizations with appropriate expertise and influence.

Eight CSI RD&D projects conducted work explicitly designed to influence standards or rules in the solar industry. Key project outcomes that relate to standards and rules include the following:

- **Revision and development of new standards for solar inverters and interconnection.** Specific projects have resulted in revisions or information for multiple standards, and testing certifications including:

- UL1741 SA - tests and certifies inverters and other utility interconnected distributed generation (DG) equipment for grid support functions enabling smarter, safer, reactive grid interconnection (Project 25).
    - IEEE 1547a Amendment establishing updates to voltage regulation, response to area electric power systems abnormal conditions of voltage and frequency, and considering if other changes to IEEE Standard 1547 were necessary (Project 25).
    - IEEE 1547 Full Revision providing a uniform standard for the interconnection and interoperability of distributed energy resources (DER) with electric power systems (EPS). The standard provides requirements relevant to the interconnection and interoperability performance, operation, and testing, and to safety, maintenance and security considerations (Project 25).
    - IEC 61850-7-420 and IEC 61850-7-520 revisions in TC57 WG17 establish communication and information exchange protocols for interconnected DER technology (Project 25).
    - IEC 62108 standard for concentrated photovoltaic (CPV) module qualification testing defines testing protocols for CPV technology designed to detect CPV module failures associated with field exposure related to thermal fatigue-related failure mechanisms for the assemblies (Project 10).

- **Improvement to the existing CPUC Rule 21 (CA Rule 21).** CA Rule 21 describes the interconnection, operating, and metering requirements for generating facilities connected to the distribution system over which the CPUC has jurisdiction. The rule includes a requirement for additional screening studies to be performed on circuits where penetration of solar PV exceeds 15 percent of peak load. The additional screening studies requirements were often unclear, and the rule did not include considerations for smart inverters or battery storage. As of June 2016, the rule has been updated to include considerations of smart inverters and storage, and includes fast tracking of new solar projects meeting specific requirements. Many of the improvements were derived from CSI RD&D project research including specific improvements related to PV interconnection limits (Projects 19, 25, 28), project screening (Projects 18, 19, 25), and costs and processes for energy storage systems (Project 26). These changes helped streamline the review process for interconnection and storage projects, and played a direct role in the improvement to the existing CA Rule 21.
- **Changes to the PG&E interconnection process.** CSI projects have resulted in enabling the quick interconnection of certified inverters rated less than 1 MW, potentially streamlining and reducing the cost of applicable projects (Project 18).

Stakeholders and experts interviewed highlighted the influence of the program projects as of high importance, suggesting that these efforts have provided critically essential information and guidelines to help accelerate integration of solar PV and help California meet its renewable energy goals. Regarding new and improved protocols and standards, interview subjects suggested that these industry-led processes helped advance knowledge of advanced smart inverters among key industry personnel.

Comments from stakeholders include:

> *"They (protocols and standards) will certainly impact inverter manufacturers and communications companies, and should help other balance of systems and component manufacturers develop products in the future having standard communication language and testing protocols"*. In addition, these advances *"should lead to a safer, more reliable, modernized grid and make it easier for smart inverter manufacturers … all this should reduce costs of DER"*.

Concerning efforts to improve CA Rule 21, regulatory stakeholders noted that in 2008, at the start of the CSI RD&D solicitation process:

> *"With regard to Rule 21 and the 15 percent peak load threshold, we didn't know … what the limits would be on the existing grid. So with aggressive mandates for increased solar on the grid there needed to be research into how much solar the grid could handle. A number of the projects were relevant to our work on Rule 21 and overall, we found a high value in terms of pushing ahead with grid integration and becoming comfortable with pushing limits on the grid."*

Another stakeholder noted:

> *"You can tell that the program had an impact because if there wasn't positive progress with these programs then we wouldn't go from a 33 percent to 50 percent penetration goal. The regulators' exposure to the outputs of CSI and other research doing this has helped the regulators, grid operators, and utilities be more sure about the impact of distributed energy resources on the grid, and I think that they feel comfortable now, and this definitely has helped advance the opportunity for higher penetration."*

Impact of recommendations on inverter system communication protocols

Advanced smart inverters are communication enabled inverters that can improve communication between distributed solar resources and the grid, helping to manage distribution of generation to the grid, cope with distribution-level voltage deviations, and provide additional protection and resiliency to the electric power system. These capabilities can be provided at potentially low cost but can greatly increase the penetration of PV and other renewable energy on the grid. Harnessing these capabilities required better understanding of the capabilities of smart inverters, how to calibrate inverters to take optimal advantage of these functions, and how smart inverter functionality can interact with distribution-level interconnection rules and regulations for electric generators and electric storage resources. Beyond the influence on specific inverter standards mentioned above, several projects provided important guidelines and recommendations for inverter systems settings and protocols to advance the integration of advanced smart inverters and help increase interconnection limits, thereby increasing the penetration potential of solar PV.

Key outcomes in this area include:

- **Demonstration projects of advanced smart inverters**. These demonstration projects provided real world evidence of how advanced communication-connected inverters and communication protocols can help progressively increase PV limits on distribution circuits, pushing limits beyond 15 percent and potentially as high as 100 percent. In some cases, they also provide ongoing test beds for future studies. (Projects 27, 29)
- **Technical reports providing guidelines and inverter settings**. Several projects developed technical reports designed to instruct utilities on how to optimally calibrate both existing inverter technology and smart inverters to integrate high levels of distributed PV. (Projects 2, 6, 18, 28)
- **Studies and analysis to develop optimal control methods**. Multiple projects conducted studies to test the application of settings of smart inverters and develop specific control methods. These control methods help mitigate against voltage variability inherent with high penetration levels of PV. (Projects 2, 6, 29)

Again, stakeholders and experts agreed that inverter system communication protocols and control methods are key to incorporating high penetration PV, and the project outputs have provided valuable data on the ability of advanced inverters and communication protocols to improve system reliability. In addition to comments mentioned in the standards section above, with regards to inverter standards, communication and control strategies and protocols were also seen as critical advancements of the Program.

One stakeholder explained:

> *"The reason this was critically important unlike other equipment in the utility industry where the utility is the buyer and owner of all equip. So there is no standard, which is ok because they simply pick one vendor and only use that one. In the case of solar or distributed resources of all types … they are owned by the customer and the customer picks. New companies are appearing and old companies are disappearing. So to be able to create a network that connects millions of these together that can monitor them cohesively and manage them consistently requires a standard communication interface."*

One solar expert, independent of the Program, stated that the industry has:

"…been looking at the communication standards in EV and inverters with building loads and with storage, indicating this is an area of importance, and the CSI projects gave us a look in to some of the challenges that we need to overcome when we start implementing these requirements for communications with smart inverters, so it has provided very valuable information for us and I think for the everyone involved".

Improvement in system reliability brought by new models, tools, and software

Across the 20 projects with Grid Integration components, there were over 30 outputs including commercialized software packages, modeling methodologies, open source modeling tools, data collection tools, and databases. These outputs have led to improvements in grid reliability in situations with high penetration PV. Examples of outputs and their effect on grid reliability include:

- **New or enhanced software products for grid planners and operators.** Several software products were developed that improve resource visibility, provide more accurate prediction of generation, and allow grid planners to model economic value of planned solar generation resources. Improvements in these areas add to overall system reliability. Some examples in this area are:
    - CPR's PVSimulator™, FleetView™, and WattPlan® tools are commercial products developed based on research from the CSI RD&D projects. According to project partners, the CSI RD&D projects "set the stage, which helped us develop a project to get to a saleable technology". Numerous utility and other stakeholders including CAISO utilize these products for grid planning and operations. Together, these tools provide single system and fleet level modeling services that use hourly resource data and defined physical system attributes in order to simulate configuration- specific PV system and fleet outputs to support utility and ISO planning and load-balancing requirements. In addition, they incorporate value analysis tools that allow users to evaluate the economic value of PV system scenarios at very low cost. A project stakeholder explained that the most important thing that this led to was "a system to help do behind the meter PV forecasting, which addresses some of the uncertainty that the ISOs feel." (Projects 1, 21, 37)
    - The Sacramento Municipal Utility District (SMUD) and Hawaiian Electric Company (HECO) with a team of industry partners developed high resolution data monitoring and evaluation efforts leading to the development of data visualization software tools that are being utilized and updated in Hawaii. These tools continued to be refined and commercialized through efforts by the U.S. DOE Sunshot program and the industry partners that have implemented some aspects into energy management systems used by a number of western utilities including the California IOUs and the CAISO, as well as utilities in Hawaii. Project partners and stakeholders believe that these products had a

highly positive impact on grid planning and grid reliability, and some of these outputs have provided significant net benefits to their organizations. (Project 5)

    - Southern California Edison and its industry partners developed a process for a stochastic distribution planning process that models distribution circuits in GridLAB-D, an open source software platform, forecasting PV adoption, determining native limits, and providing mitigation strategy analysis for interconnection of new PV generation systems. These tools have been integrated into the Qado Systems software platform GridUnity that provides a user-friendly graphical interface and visualization tools. Utility stakeholders using these platforms explained this software tool was something that did not exist prior to the project and is proving very useful in its ability to demonstrate mitigation processes, model native distribution circuit limits, and expedite the screening process for new projects, which all contribute to grid reliability. (Project 29)

- **Enhanced data products providing critical solar irradiance and other data** that can be integrated into existing modeling tools or software to improve generation visibility, predictive capabilities, and economic assessments, including:
    - SolarAnywhere, a solar resource database containing over 14 years of time- and location-specific, hourly insolation data throughout the continental U.S. and Hawaii. Through a series of CSI projects, these data were enhanced to provide the highest known resolution of any satellite-based irradiance data set in the world, with a 1 km x 1 km, 1- minute resolution. These data were publicly available to users and are used by a broad array of stakeholders around the world. (Project 1)
    - SMUD installed an irradiance sensor network within its territory and integrated the resulting data into its existing planning system to enhance planner visibility of solar generation capacity. Utility staff stated that the sensor network and data have been very important for increasing PV penetration in its service territory and to show utility leadership "that this could be [the] future for us". (Project 5)

- **Improved modeling tools and methodologies.** Aside from specific software applications, several projects developed modeling tools in open source modeling tool and modeling methodologies that can be adopted or integrated into existing utility planning and operations tools. These included tools and methodologies for solar irradiance forecasting, generation forecasting for individual systems and fleet systems, distribution system models, and economic value modeling tools. Each of these types directly or indirectly lead to benefits in system reliability through, for example, more accurate predicting of solar generation and optimal siting of generation resources. Some specific examples of outputs include:

- A PV performance model that can be applied to satellite solar irradiance data to simulate PV power output taking into account local weather conditions. The model uses SolarAnywhere data and is shown to accurately predict power output to within 3 percent of actual output. The model is provided in MATLAB and can facilitate power conversion modeling for large datasets for variability or forecasting applications. (Project 4)
- Cloud speed algorithms to help forecast transient cloud cover, which is an important variable in estimating PV power output. Two different methods to determine cloud speed were developed by a series of projects as well as innovative cloud speed sensor hardware. (Projects 4, 22, 30, 33)
- A novel PV adoption methodology was developed that estimated the probability of adoption of distributed solar attached behind the meter in residential and commercial applications. The method was developed to simulate allocation of new solar PV installations as penetration levels increased, in order to inform forecasts of future states of distribution systems. The method was shown to provide more accurate PV adoption in terms of installed size and location than has been modeled before at scale. (Project 29)

Discussion with stakeholders, experts, and market actors indicate that these program outputs have led to greater system reliability, or a better understanding of actual system reliability that has led to a higher degree of confidence in the ability of the California grid to integrate higher penetrations of distributed PV.

One stakeholder noted that:

> *"Projects I was involved in had a major impact with understanding risks, lots of grants did work with simulating higher penetrations than what is currently being absorbed and allowed utilities and stakeholders to understand the grid impacts as solar penetrations continue to increase."*

Another stakeholder stated:

> *"The generation mix has potentially changed as a direct result of projects increasing the reliability of the grid."*

Reduced cost, saved time, and lowered risk of new projects and system operations

Upfront costs are the single largest barrier to widespread adoption of solar distributed generation technologies. A major component of up-front solar costs are soft costs, which the DOE estimates at 64 percent of total solar costs.[12] Three areas of potential soft cost reduction from the customer side are optimized solar project design and integration with energy efficiency or demand response measures, faster approval and interconnection of new solar projects, and reduced costs of interconnection studies. From the utility side, soft costs can be reduced through improved system operations to incorporate new solar PV, as well as potential maintenance and repair costs that can be avoided through mitigating the risk of new solar projects.

A goal of the CSI RD&D Program was to identify projects that would lead to lower upfront costs to increase penetration of solar PV. Several of the outputs already mentioned have made significant advancement toward these goals either directly or indirectly in conjunction with meeting other goals. There are also outputs directed specifically at reducing the cost and time taken for new projects and lowering the risk of projects to system operations. Examples of important outputs meeting these goals include:

- **Software products promoting optimal building design and integrated projects.** In theory, optimal building design and integrated projects should help reduce the installation costs of solar PV, through ensuring buildings are energy efficient and solar PV is optimally sized. The program funded a project to enhance the NREL BeOpt building design and simulation software application to facilitate the identification and implementation of balanced, optimal, and cost-effective integrations of energy efficiency, demand response, and PV in the residential retrofit and new construction market, including multi-family housing. An important functionality of the program is appropriate sizing of solar PV systems based on cost effective energy efficiency measures installed in the home. The program also funded the Integrated Energy Project XML Schema project that developed a common data collection and communication protocol for common communication across software platforms. Both projects have the potential to significantly reduce costs and save time related to solar PV installation. (Projects 7, 8)
- **Recommendations for Interconnection Regulations and Rules**. Four projects developed recommendations updating either utility level interconnection processes, or recommended modifications for CA Rule 21 based on the technical analysis conducted as part of the projects' scopes. The recommendations from two of these projects (18 and 19) are known to have played a direct role in the improvements to the existing CA Rule 21. Other projects are likely to have influenced these changes. (Projects 6, 18, 19, 20)

[12] U.S. DOE. 2016. Soft Costs 101: The Key to Achieving Cheaper Solar Energy. https://energy.gov/eere/articles/soft-costs-101-key-achieving-cheaper-solar-energy

- **Mitigation strategies to avoid or control faults related to new solar PV installations.** Interconnected solar PV projects come with risks to the grid, including voltage variation causing circuit overload or voltage drops that can negatively impact grid operations. Several projects developed mitigation strategies at system and grid levels to avoid these risks. Implementing mitigation strategies can reduce operations costs, as well as offset future maintenance or repair costs. (Projects 5, 6, 20, 29)

We asked stakeholders and experts outside the projects to discuss the value of efforts to reduce costs and risks of new projects and save time through accelerated project approval. Interviewees noted cost of solar projects as one of the primary barriers to adoption of solar PV, and soft costs of solar as one of the main potential areas of cost reduction. These interview subjects stated that the CSI project outputs have made inroads into reducing costs, saving time and lowering risk of new projects and system operations, with one stakeholder noting that:

> *"We are seeing significantly lower prices and higher performance and better configuration and training and everything to make things cheaper which wouldn't have happened without structured multi year programs like CSI".*

Evidence of simpler/streamlined interconnection requirements

A focus of several projects was developing screening methodologies and models to help simplify and streamline PV project interconnection requirements, which are a cost to solar projects. Given that only a short time had elapsed since these projects were completed, we did not observe any specific examples of where the projects had a direct effect on changing interconnection requirements. However, several projects developed tools or models that have good potential for providing improvements in these areas. Examples include:

- **Simulation models and methods to estimate power output of PV fleets or individual projects over high speed time intervals** can help grid planners perform detailed grid integration studies and identify optimal siting locations of PV. Screening studies often have to be conducted to install new solar PV projects, particularly on high penetration feeders. These methods can help streamline these efforts.
- **Detailed feeder models and new software to enhance utility planning models** have resulted in improved methods that will allow utilities to more quickly and accurately perform engineering screens for new interconnection requests of solar PV, thus reducing time and costs associated with interconnection studies.
- **Project screening methodologies and software tools** developed under the project are designed to help optimize location of new PV generation resources in a streamlined cost effective manner.

Lower transaction costs for implementing solar projects

One specific area of soft costs that has a high impact on overall solar system costs is transaction costs related to new solar projects. Transaction costs include costs of permitting and costs for interconnection studies or other reporting requirements, among others. Again, many of the outputs mentioned in previous sections have had or could have an impact on transaction costs through improved siting of projects, improvements to standards and rules, and developing a better understanding of the impact of solar PV on the grid. Many project outputs including forecasting models, improved smart inverter protocols, and screening methodologies have already or have the potential to lead to reduced transaction costs for interconnected solar projects. Some examples include:

- **Analysis conducted to inform California grid integration rules** that evaluated a set of advanced inverter methods and settings and developed a complete set of guidelines and recommendations provides a mechanism to improve the distribution system performance (as it relates to voltage) when accommodating higher levels of PV. These methods can help fast track application and therefore reduce costs and achieve higher penetrations of solar PV.
- **Improved project interconnection screening and methods for high penetration PV studies**. Projects developed detailed methodologies for performing high penetration PV studies. Utilities use these types of studies to determine interconnection approval status of new projects. (Projects 2, 5, 6, 19, 29)

We asked stakeholders and experts to discuss the value of project outputs designed to help improve costs of implementing new solar projects. These interview subjects stated that CSI projects provided needed and valuable information to help streamline approval of new solar projects, which leads to lower costs.

One stakeholder noted that the projects have made interconnection:

> *"much more simple and gave utilities tools to solve problems, [and] allowed more interconnections without expensive upgrades".*

Another explained that:

> *"The tools provided by projects are really pretty good at expediting (the approval) process and improving the time of the screening process".*

6.2.2 Grid Integration Medium-Term Outcomes

The Grid Integration projects also achieved progress with some of the medium-term logic model outcomes (5-10 years) summarized in Table 9 even though most of these projects were completed less than five years ago. Because a relatively short time has elapsed since the completion of these projects, we would not expect to see much progress on the medium-term progress metrics from the logic model. Despite the short timeframe, our evaluation research did find indications that progress was made in these areas, with good potential for continued progress in the future. For these reasons, we give a "medium" assessment of progress for these metrics in Table 9, which would likely be changed to "high" after more time elapses.

Progress on the Grid Integration medium-term metrics is summarized at a high level below, with a more detailed discussion provided for each metric in Appendix C.

Table 9: Grid Integration Medium-Term Outcomes – Metrics and Progress Assessment

Key Logic Model Metric	Progress Assessment
Medium-Term Outcomes (5-10 years)	
System improvements allowing greater visibility of solar generation	Medium
Improved project value, interconnection time, project approval	Medium
Encourage streamlined approval processes	Medium
Increased expectation of simplified rules and standards	Medium
Increased expectation of improved technical guidelines	Medium

The Grid Integration medium-term outcomes tend to focus on increasing the visibility of solar generation, improving the estimated value of new projects, and improving the perception among stakeholders that the projects will reduce costs and streamline approval and implementation processes (improved perceptions in these areas increase the likelihood that the RD&D results from these projects will be utilized in the industry). The perceived value of the Grid Integration projects was also confirmed by our broader survey of solar market actors when asked to assess the potential benefits of some representative projects. The outputs from several Grid Integration projects are being used in operational environments by multiple utilities as well as the California ISO, thus confirming their value to the industry.

We asked stakeholders and experts outside the projects to discuss the value of efforts for better visualization tools undertaken by program projects. These interview subjects highlighted generation visibility as an area of need in the industry.

One stakeholder noted that before the CSI RD&D Program began, there were:

"inadequate modeling and forecasting tools for distributed generation and these were needed to help predict and understand the impact of high penetration distributed generation resources".

Another stakeholder explained that in 2008 a major barrier to high penetration PV was *"basically not having good forecast data for multiple locations at high time resolution".*

Across these interview subjects, there was a common agreement that there has been significant advancement made in this area, and the CSI RD&D program has made important contributions. One stakeholder noted *"we are at a very different point as a state as regulators and planners in our understanding of optimal siting, and in our understanding of visibility, and solar loading"* and attributed some of this advance to the CSI RD&D program projects.

We asked stakeholders and experts to discuss the value of project outputs designed to help improve or expedite the utility interconnection process. Again, these interview subjects were generally of the opinion that these CSI RD&D projects provided needed and valuable information to help improve the interconnection process and associated rules.

One stakeholder noted that the projects have made interconnection *"much more simple and gave utilities tools to solve problems, allowed more interconnections without expensive upgrades".* A utility stakeholder explained that for interconnection, utilities *"have to go through some technical screens to determine the impact of some PV stuff and what we do today is more or less manual. So I think the tools provided by projects are really pretty good at expediting that process and improving the time of the screening process".*

A regulatory stakeholder noted that *"the gap for these projects was that the existing screening practices needed improvement and weren't as effective as they could be for high penetration scenarios. Meaning that the timeliness of having screening done as well as the effectiveness of the screening practices was poor. The program helped fill this gap related to screening practices improvements".*

7 Solar Technologies

The success of the overall CSI Program depends on increasing performance and efficiency of solar technologies in the market. To support this goal, the CSI RD&D strategy adhered to seven key principles, which included improving the economics of solar technologies by reducing technology costs and/or increasing system performance, focusing on issues that directly benefit California that may not be funded by others, and overcoming significant barriers to technology adoption. Barriers include high up-front cost, which remains the single largest barrier to widespread adoption of solar technologies, as well as other barriers such as unproven technological performance, and proof of economic value. By targeting RD&D activities at those barriers or opportunities that promise high impact but are currently under-funded, distributed solar applications could become more widespread.

The *Solar Technologies* projects had varying levels of success with several projects meeting all their stated objectives. Other projects, however, did not meet their objectives or invested in technology that proved not to be viable in the market.

To address these market challenges, the CSI RD&D Program looked to improve and support commercialization of technologies that were at a near commercial stage, rather than prototype technology. The CPUC identified solar production technology development (Solar Technologies) as a key focus area for the CSI RD&D Program, where the CSI RD&D Program could provide high value for grant funds. By supporting these technologies, the overall goal to increase performance and efficiency of solar technologies and reduce barriers to market adoption should be met.

Solar technology was a primary focus in Solicitation round 2, and a secondary focus in rounds 4 and 5. These program solicitations instructed applicants to engage in activities focused on the needs or areas of knowledge gaps detailed in Table 10. In total, there were 12 Solar Technologies projects funded through the CSI RD&D Program. The following tables summarize these Solar Technologies project characteristics and accomplishments.

Table 10: Solar Technologies Needs And Knowledge Gaps

Area of Need	Description
Projects demonstrating "economic viability of distributed concentrating PV systems"	The CSI RD&D strategy identified CPV systems as an important technology for the success of the CSI program. Distributed solar is currently constrained by the size of a roof or available land to site the system. More efficient solar cells, inverters, and wiring solutions will decrease the overall size of the system thus allowing greater potential for more generation.
Projects that help "building integral PV products (BIPV) become competitive with rooftop PV" and which address "key technical integration issues"	Developing innovative PV materials or methods of integrating PV into buildings are also highly promising methods of reducing the cost of PV systems and/or expanding the market for them, by, among other things, reducing material and production costs and allowing more of a building's surface to be used.
Testing and demonstrating inverter technologies that improve reliability or performance of solar systems and help lower costs	Inverter technology has potential to enhance adoption of solar technology through mitigating the impact of solar penetration on the grid, and increasing control over power flow from solar PV to provide value to utilities and ratepayer. The CSI RD&D Program focused on advancing inverters that demonstrate longer periods between failures, demonstrate lifetimes approaching the expected twenty-year lifetimes for modules, have lower capital costs and lower operating and maintenance costs, and have better integration with smart meters
Testing and demonstration of existing energy storage technologies capable of working with smaller solar systems and that allow the end user or utility to capture higher value from the energy produced (e.g., provide energy during peak).	Solar storage technology has the potential to convert solar PV resources into reserve resources. To support progress to this goal, and to improve value of solar to utilities and ratepayers the CSI RD&D Program encouraged near-term testing and demonstration of innovative energy storage technologies, storage technologies suitable for community or multi-user applications, and solar thermal/electricity storage systems recently developed under DOE funding
Field-testing and demonstration of innovative hybrid-solar technologies. Possible examples include:	Solar thermal/solar electric technologies that can increase the economic or greenhouse gas benefits being provided by current solar technologies Concentrating solar systems that can increase production for larger commercial applications. Solar/non-solar combinations (e.g., fuel cells/solar applications) may help competitively extend energy benefits provided to end users

A total of 12 of the 34 completed projects included a solar technology improvement or advancement component (see Table 2). Across the 12 projects, 27 discrete outputs were delivered to meet the identified industry needs. Table 11 presents a summary of the program identified needs and the projects that developed outputs that were designed to meet those needs.

Table 11: Knowledge Gaps and Areas of Need and Corresponding Project Activities

Area of Need or Knowledge Gap	Project ID	Key Project Activity Examples
Projects demonstrating "economic viability of distributed concentrating PV systems"	10, 17	• Manufacture and installation of concentrating PV systems, • Modeling and analysis tools developed for concentrating PV • International standard developed • Installation and demonstration of innovative concentrating photovoltaic / thermal co-generation (CPV/T-2G) technology,
Projects that help "building integral PV products (BIPV) become competitive with rooftop PV" and which address "key technical integration issues"	27, 35	• Enhancement of existing building modeling software • Construction of demonstration sites of 20 ZNE homes
Testing and demonstrating inverter technologies that improve reliability or performance of solar systems and help lower costs	25	• Development of smart inverters and accompanying communication protocol
Testing and demonstration of existing energy storage technologies capable of working with smaller solar systems	9, 14, 15, 26, 36	• Development and demonstration of new energy storage technology • Development and deployment of control software
Field-testing and demonstration of innovative hybrid-solar technologies	9, 11, 14, 37	• Development and demonstration of hybrid solar technologies Installed and monitored a 110 kWp photovoltaic tracking system • Field testing performance of hybrid solar technology
Other	13, 16	• Development and demonstration of other innovative solar technology • Development and deployment of software system that automates the BOS component engineering and documentation for optimized PV array

A summary of some of the key Solar Technologies project outputs is provided in Table 12. Outputs include 11 hardware technologies, including Concentrated PV, storage, and hybrid PV technologies; five software platforms; and eight demonstration sites.

Table 12: Solar Technologies Outputs by Project

Solicitation - Project ID	Output Type	Output Description
2 – 9	Technology - Hardware	Advanced energy storage system: ice energy (thermal storage).
	Demonstration	Demonstration and field test for Ice Energy thermal storage.
2 – 10	Technology - Hardware	Amonix high concentration photovoltaic (HCPV) system
	Demonstration	Amonix manufactured and installed 2 CPV units rated at 113 kw as demonstration sites at UC Irvine
	Modeling Tool	UCI's APEP developed a central power plant and CPV dynamic models for system operation.
	Standard	International standard defines a test sequence to detect CPV module failures associated with field exposure to thermal cycling
2 – 11	Technology - Hardware	Solaria modules: single axis, dual axis and polar axis
	Demonstration	Two demonstration sites with solaria modules, a 110 kWp system at the solaria manufacturing facility in Fremont, CA and a 240 kWp system installed at alameda county Santa Rita jail in Dublin ca.
2 – 13	Technology - Hardware	Low-cost P&P PV Kit - "plug & play" AC micro-inverter PV system.
	Demonstration	Installation in six test homes. Updates to installation protocol and P&P PV kit after prototype install. Installation, monitoring and performance evaluation of the installations
2 – 14	Technology - Hardware	Battery buffered electric vehicle charging station
	Technology - Hardware	Second-life batteries for application in single family homes
	Technology - Hardware	Innovative hybrid photovoltaic/thermal (PVT) technologies and designs for solar hot water in multifamily and single family applications
	Demonstration	Demonstration site with installations of three technologies
2 – 15	Technology - Hardware	Develop advanced stationary battery product combining tesla motors' vehicle battery with Solarcity's SolarGuard dispatch and monitoring platform, to create a firm, dispatchable, grid-interactive,

Solicitation - Project ID	Output Type	Output Description
	Technology - Software	Advance communication and control technology platform.
	Demonstration	Demonstration of communication and control technology platform and advanced lithium-ion battery storage technology at six sites
2 – 16	Technology - Software	Automated array design and engineering software for rooftop solar installations - Sunlink Design Studio (SLDS)
	Study	Seismic testing and analysis of rooftop solar arrays
2 – 17	Technology - Hardware	Hybrid concentrating PV/thermal tri-gen (CPV/T-3G) technology
	Demonstration	Demonstration system installed at Sonoma Wine Company in Graton, CA rated at 272kw.
4 – 25	Technology - Software	Inverter communication driver software that bridges the field bus protocol used by the inverters (Modbus) to the wide area network protocols used by the utility network (IEEE 2030.5 and OpenADR).
	Technology - Software	Test framework software, including test scripts and test lab automation technology, to test inverters complying with CA Rule 21
	Technology Hardware	Prototype advanced smart inverter
4 – 27	Demonstration	Demonstration of cost effective technology pathways for ZNE communities
5 – 36	Technology - Hardware	Comprehensive system assessment of the smart grid-tied energy storage system using second-life lithium batteries
5 – 37	Technology - Software	Development and delivery of an interactive software platform that provides actionable insights regarding plug-in electric vehicles

Overall, the CSI RD&D Program projects had varied success in developing and demonstrating viable pre-commercial solar technologies and helping them advance to market. Of 12 projects that included a solar technology improvement or advancement component, two are likely to have long-term market impacts in terms of direct sales of new technology, with several others having the potential to have indirect impacts on the market in terms of knowledge transfer. However, the two projects that are likely to have long-term impacts are likely to have significant impacts on the development of battery storage and on reducing soft costs of mounting units and permitting.

While CSI RD&D Grid Integration projects nearly all met or exceeded their objectives, some of the Solar Technologies research area projects struggled to meet their objectives for a variety of reasons. This is not entirely surprising, as development and demonstration of technology can often face more hurdles than some of the more research-oriented outputs associated with the Grid Integration projects. While there were some projects that struggled, there were also some notable strong successes.

Project outputs all have a development lifecycle that includes initial concept development, testing, and validation of performance in operational environments and industry adoption. Once adopted, the outputs should have effects on the adopting organizations and the industry more broadly, including lower generation costs, increased competition in the market, and clean jobs. However, identification of solar technology project effects on the CSI RD&D Program is made difficult due to the varying development stages of the outputs due to the design of the program, with projects from earlier solicitations available to the industry for longer than outputs from later solicitations, including some outputs that have been available for less than one year. Despite these challenges, we are able to identify projects with significant success and subsequent market uptake, as well as projects that were less successful.

Below, we provide a summary assessment of how well the Solar Technologies projects performed relative to the market outputs identified in the logic model for this research area. The remainder of this section provides a summary, with a more detailed version of this section included as Appendix D.

7.1 Assessment of the Solar Technologies Project Outputs Relative to the Logic Model Progress Metrics

7.1.1 Solar Technologies Short-Term Outcomes

The short-term (0-4 years) outcomes are those milestones identified in the logic model that signify early progress toward achieving the overall program goals. Progress made in these initial areas for the Solar Technologies projects would indicate that the Program is on the right track, at least for this project group.

Table 13 summarizes our assessment of the progress made on the short-term Solar Technologies metrics, with additional discussion for each metric following the table.

Table 13: Solar Technologies Short-Term Outcomes – Metrics and Progress Assessment

Key Metric	Progress Assessment
Number of technology outputs with documented performance characteristics in operating environment	16
Number of technology outputs installed or applied commercially	11
Stakeholder acceptance/perceived reliability.	High
Validation of objective performance characteristics in operating environment	High
Sales / transfer of ownership of hardware/software (i.e., sales of product license –for open/free public use or privately held)	Medium
Increased technology production, sales, and/or revenues, and installations	Medium
Full scale technology production, ongoing growth of installations	Medium

Number of technology outputs with documented performance characteristics in operating environment, number of technology outputs installed or applied commercially

The Solar Technologies project results (outputs) have a development lifecycle that includes development, testing, and validation of performance in operational environments, and industry adoption. Of the 16 hardware and software technologies investigated under the CSI RD&D projects, 11 were specific products being field tested and improved with a view to some form of dispersion to the wider market, either as proprietary products, or as open source or public resources. The remaining five technologies were being field tested to determine viability in specific applications. Of the 11, which include six hardware technologies and five software technologies, all have had some form of broader installation in the market. However, three of the hardware technologies—Amonix CPV, Cogenra's Tri-Generation technology, and GE's Plug-and-Play AC PV panels—have been discontinued. The three remaining hardware technologies, the SolarCity/Tesla lithium ion battery storage technology, Solaria's low cost solar PV panels, and Ice Energy's ice battery have all seen high degrees of market adoption relative to their applications. The five software technologies have each been applied commercially to some extent.

Stakeholder acceptance or perception of reliability

Where possible, the evaluation team asked stakeholders and experts for their assessment of the technologies, whether they perceived the technology as reliable or not, and whether they accepted the results of the studies as reliable, based on the project outputs. It was not always possible to identify a specific stakeholder for each technology, in which case we relied on the combined perception of the grantees and the Program Manager, Itron.

Stakeholders and experts were provided with website details for the CSI RD&D Program where they could access project documentation prior to the interview. They were not explicitly instructed to review these materials, however. Stakeholders were asked to answer the following questions:

> *How successful were the projects in addressing and resolving the knowledge gaps they intended to close?*
>
> *Have any of the projects you were involved in led to, or are likely to lead to, new technologies, new services or businesses, new methods of manufacturing, marketing or delivering technologies?*

Interviewers probed further with stakeholders who mentioned technology projects to ascertain their perception of the technology reliability and potential.

Table 14 below presents an assessment of stakeholder, grantee, or program manager acceptance or perception of reliability. Each project received a score of 1 to 3, where a score of 1 represents low acceptance or perception of reliability and a score of 3 represents high acceptance or perception of reliability. The scores assigned to stakeholders and grantees were assigned by the Evergreen team based on the qualitative response from the interview subject. The score provided by Itron staff is an actual numeric score provided by the project manager.

Table 14: Stakeholder Acceptance or Perception of Reliability Score

Solicitation - Project ID	Stakeholder Score	Grantee Score	Itron Score	Average Score
2 – 9		2	1	1.5
2 – 10	2		1	1.5
2 – 11		3	2	2.5
2 – 13		3	3	3
2 – 14	3		2	2.5
2 – 15	3	3	3	3
2 – 16	3	3	3	3
2 – 17			3	3
4 – 25	3	3	3	3
4 – 27	3	3	3	3
5 – 36		2	2	2
5 – 37		3	3	3
Average Score	**2.83**	**2.77**	**2.42**	**2.58**

With the exception of five projects, stakeholders, grantees, and the program manager, on average perceived the results of the projects, as well as the technologies, to be reliable.

Validation of objective performance characteristics in operating environment

Each of the technologies in the 12 projects underwent field-testing and validation either in an operational or demonstration site environment. The only exception is Project 25, which is a recently completed project for which the software outputs have to date only been applied in a laboratory testing environment.

Ten of the 12 projects performed as expected by the project teams. Some notable findings and progress include:

- Producing the first international lifetime reliability standard for CPV. (Project 10)
- Showing that Solaria's Low Concentration PV technology works best in high irradiance environments by design, but still performs in cloudy or overcast environments when a high concentration ratio technology would shut down, and proved that soiling does not affect the Solaria module in any manner that would be

quantifiably different from standard modules, as far as power output is concerned. (Project 11)

- Providing a solid proof of concept and practical implementation for Grid-Ready Plug-and-Play PV Kits and demonstrating that this technology can be installed entirely by a trained roofing contractor. The GE version was estimated to have an installed cost below $4/watt, assuming a 1,000-unit production volume, this being well below the target cost. Testing also found that AC P&P PV Kit arrays are relatively insensitive to shading, compared with the typical DC string arrays. This could be a very important factor to energy production and cost-effectiveness in the retrofit market, where shading is a prevalent problem. (Project 13)
- SolarCity and Tesla were able to design, develop, and install both residential and commercial advanced lithium ion products. Throughout the process, there were many insights gathered on important product specifications, code requirements, installation processes, and customer feedback. These insights have influenced various policy and regulatory settings that are currently determining the future of paired PV and energy storage products, including conducting a series of UL site certifications, leading to draft standards for integrated storage products. (Project 15)

Sales/transfer of ownership of hardware/software (i.e., sales of product license–for open/free public use or privately held)

As noted in the proposed CSI RD&D Plan, "success of the CSI program depends on increasing performance and efficiency of solar technologies in the market." In the adopted CSI RD&D Plan, production technologies are those "supporting commercialization of new PV technologies." An indicator of success of production technologies is whether they progress to being commercialized technologies, and experience some sales volume or licensing. This metric (and the following three metrics) addresses the level of commercialization of products from initial sales and/or transfer of ownership of products, to increased technology production, and on to full-scale production. This metric measures if there have been any initial sales of technology, use of software, or transfers of ownership or technology licenses for the sharing of knowledge or technologies, with a wider range of users who can then further develop and exploit the technology into new products or processes.

Table 15 shows which projects have either had initial sales of products or have engaged in any form of licensing or knowledge transfer leading to development of products by other parties.

Table 15: Initial Sales Of Products Or Licensing or Transfer Of Knowledge

Solicitation - Project ID	Product Has Commercial Sales	Project Output has Licensing or Transfer Of Knowledge Leading to Other Product Development
2 – 9	Yes	No
2 – 10	Yes	Yes
2 – 11	Yes	Unknown
2 – 13	Yes	Yes
2 – 14	No	No
2 – 15	Yes	Unknown
2 – 16	Yes	Yes
2 – 17	Yes	Unknown
4 – 25	No	Yes
4 – 27	N/A	N/A
5 – 36	No	No
5 – 37	Yes	Unknown

Eight of the twelve projects have had at least one commercial sale of a product indicating a high initial success rate (~66%) of moving pre-commercial technology to validated commercial technology.

Increased technology production, sales, and/or revenues

The next stage of assessment is whether a technology has moved beyond initial commercial sales and experienced increased investment in production, increased sales, or increased revenues. Because of the late stage of several projects, we only assessed the progress in this metric for projects from Solicitation 2. We reviewed the project final documentation, spoke with stakeholders and market actors, and conducted Internet research to determine if technology experienced increased sales or production beyond initial commercial sales. Table 16 presents an assessment of increases in sales after the program participation ended, for each project in Solicitation 2.

Table 16: Initial Sales Of Products Or Licensing or Transfer Of Knowledge

Solicitation - Project ID	Increased Production or Sales	Description of Increased Production or Sales
2 – 9	No	While Ice Energy continues to manufacture and sell its technology successfully (over 1000 units installed), Sunpower did not partner with any of the storage partners to develop technology. Sunpower did take lessons learned from the project and apply it to new technology but there were sales connected to this project explicitly.
2 – 10	Partial	From the start of the project Amonix installed approximately 50MW of CPV globally, however, Amonix was liquidated in 2014 before the end of the project and assets purchased by Arzon Solar.
2 – 11	Yes	Developments in the project led to installation of approximately 30MW worldwide, but only 1 MW installed in California. Solaria developed additional products partly based on lessons learned in this project including NEXTracker
2 – 13	No	GE stopped production of the Grid-Ready Plug-and-Play PV Kits before commercialization. Other industry manufacturers have similar products such as LG.
2 – 14	No	No
2 – 15	Yes	SolarCity and Tesla partnered to deploy 350 units of combined PV and battery storage units based directly on outputs of this project through the CA SGIP incentive program.
2 – 16	Yes	Sunlink developed a rack mounting system for flat commercial roofs that can avoid roof penetrations as a result of this project. The project provided an AutoCAD add-in tool to design the racking and tested for seismic stability, resulting in a reduction of BOS costs. The data from the seismic tests support revisions to the standards for rack mounts throughout the industry
2 – 17	Yes	The Cogenra SunPack product was installed at approximately 20 sites after the project. Sunpower acquired Cogenra in 2015 and discontinued the SunPack product. Technology developed through SunPack development is used in SunPower products including their Performance line of products.

Of the eight projects in Solicitation 2 that had a solar technology component, four saw increased production and sales after the project with products related to project research. Two of these companies were acquired by other solar companies that discontinued their products but used the technology in other commercially available products. Two Solar Technologies projects, Project 15 and Project 16, saw significant sales increases and commercially viable products. Project 15 in particular, a partnership between SolarCity and Tesla, developed technology that has led directly to Tesla's PowerWall product—their flagship residential storage product—and SolarCity's GridLogic platform and storage control software, both of which are widely used.

Full scale technology production, ongoing growth of installations

As noted above, two projects have led to full-scale technology production and ongoing growth of installations (Project 15 and Project 16). Two other projects (Project 11 and Project 17) have contributed to other technologies.

Project 15 - Advanced Grid-Interactive Distributed PV and Storage. As noted above, the technology deployed and demonstrated in this project has led directly to new products from Tesla and SolarCity. According to a stakeholder, during the grant project lifetime, Tesla took the battery storage pack and control software through one and a half generations, which led to a product that was installed in 350 homes under the SGIP program. This technology then led directly into the PowerWall and PowerWall 2.0 products from Tesla that have been available for sale since the beginning of 2015. This same stakeholder noted that:

> *"the key impact is that because of this grant funding, the deployment of residential power storage at scale was likely accelerated by some amount – arguably by a couple of years, it is a product that came to fruition that much earlier at scale"* and through the grant *"we were able to learn what were the meaningful product requirements and system level requirements for a successful residential energy storage deployment and we absolutely view energy storage as a technology that adds value to the operation of solar on the grid, it very clearly defined for us what is necessary for a battery system to be designed, owned and operated and how to reduce soft costs. Even fundamental things like that battery packs may be wall mounted in residential applications. A lot of the details that are ultimately the difference between $1000 kWh energy storage and $200 kWh energy storage".*

Another innovation was that this project saw the initial genesis of SolarCity's communication and control platform for energy storage, and learning what are the features necessary for fleet aggregate control of energy storage.

Project 16 - Reducing California PV Balance of System Costs by Automating Array Design, Engineering and Component Delivery. The project led to new and improved Sunlink products as well as products other racking system manufacturers. One stakeholder noted that:

> *"our experimental data got traction and got published and other racking manufacturers were able to use that approach as well. So we were not the only racking system on the market that could use the method – it became an option for any manufacturer to use so systems in CA became cheaper and easier to install based on our work".*

In addition, a startup company that was formed as a result of the project developed automated design software that incorporated lessons learned from the project.

Growth in solar company profitability, stock price, or improved investor sentiment

It is difficult to directly tie growth in solar company profits to CSI RD&D Program projects. One stakeholder noted that the relationship between Tesla and SolarCity that developed around the joint work on energy storage is certainly one of the reasons why Tesla has offered to buy SolarCity, which has an impact on the performance of Tesla. Tesla was expected to sell 168.5 megawatt-hours of energy storage systems to SolarCity in 2016, up from 25.8 megawatt-hours in 2015, which represents a revenue increase from $8 million to $44 million. Other companies such as SunPower and Sunlink that have developed products from the CSI RD&D Program project research are likely to see increased revenues and therefore improved company performance, but attributing any improvements directly to CSI RD&D Program projects is not possible.

7.1.2 Solar Technologies Medium-Term Outcomes

The medium-term (or second order) outcomes refer to the effects that project accomplishments have in the mid term (5-10 years). We primarily rely on a qualitative assessment based on our interviews with the grantees, industry experts, and stakeholders.

Table 17 provides a summary of our assessment of the medium-term progress for the Solar Technologies project group. In general, progress on the medium-term outcomes has been low, largely due to the fact that not enough time has passed since project completion for much progress to be made in these areas.

Table 17: Solar Technologies Medium-Term Outcomes – Metrics and Progress Assessment

Key Metric	Progress Assessment
Higher penetration of solar technologies. Greater breadth and volume of cost-effective applicability of solar systems.	Medium
Funding of new projects to develop supporting or ancillary hardware/software, dependent on the newly commercialized hardware/software	Low
New financing options offered/new business models arise for technology distribution.	Low
Increased applicability/usability of solar generation. Growth in types of projects. Shorter and more automated interconnection process.	Low/Medium

Higher penetration of solar technologies, greater cost-effective applicability of solar systems

While there are only two projects with organizations actively moving forward with technologies directly related to the CSI RD&D Program project outputs (Project 15 and Project 16), these two projects have the potential to have a significant impact on the penetration of solar technologies.

In particular, the Tesla/SolarCity partnership (Project 15) has led to development of one of the industry-leading storage products on the market that is seeing significant increases in penetration. The advancements made in this project that are likely to impact solar and battery storage penetration in the future include:

- Moving the industry toward lithium ion battery technology. As noted by a stakeholder with knowledge of the Tesla/SolarCity project, the industry

  "was not focused on lithium ion batteries (LI Ion) but were focused on other chemistries – lead acid, flow batteries and a few other tech. We found that the charge cycling and weight and form factor benefits were immensely beneficial from going to LI Ion."

- Identification of key areas of cost savings. One of the important innovations according to a grant partner was

  "a lot of cost, rather than coming from the cost of the cells themselves, comes from how the system as a whole was packaged, by that I mean not just putting cells into a battery pack but then taking that DC battery pack and pairing with an inverter, and then integrating with the grid or an energy control system. We found that there were many other groups trying to do energy storage that were two to four times the cost of what we

thought it should be and were able to prove that it should have been. It was very beneficial to SolarCity and the team, not just in things we were publicly publishing in papers but just in many, many private conversations with manufacturers across the industry….equipment, inverter, battery, cell makers: we were able to have conversations with these folks and share an example of where they should be. This has informed products that are becoming available now".

- Development of certification testing and standards for battery storage. A project partner noted:

  "when we started, the National Electric Code almost had nothing in it about certain types of energy storage especially LI Ion based energy storage systems. They had lead acid systems but these are different with regards to voltages, exposure and service. This project and our communication with NEC has informed how we asked for future changes to NEC. And same thing with UL especially on the Tesla side, there were not UL testing standards for energy storage of the type we were building. So in the project, for the first few systems we built we had to do a series of UL site certifications; these were product certifications because there wasn't a standard. So coming out of that, there are now draft standards, and the way Tesla and SolarCity have interacted with the standards bodies and advised how to form standards has come out of this work. This is a key step in commercialization of the products and outputs of the project and allows the standards body to be able to do a factory listing of the products".

In addition to this project, there were other projects that could impact future penetrations of solar technologies including work on CPV technologies in testing and developing standards around these products. For example, if silicon prices increase and/or other market factors change so that CPV technology becomes economically viable again, a lot of groundwork has been laid to help advance penetration of these products.

Funding of new projects to develop supporting or ancillary hardware/software, dependent on the newly commercialized hardware/software

Aside from the startup created to commercialize output from the Sunlink Project 16 discussed above, we are not aware of any new projects being planned to develop supporting or ancillary hardware or software to support these products. It is possible that there will be further spinoff technology or research, particularly in the software and inverter protocol sphere that will be needed to support further integration of battery storage or other technologies.

New financing options offered/new business models arise for technology distribution

We are not aware of any new financing options or business models arising from these projects aside from the Tesla/SolarCity model that is already in place.

Increased applicability/usability of solar generation. Growth in types of projects. Shorter and more automated interconnection process

The Solar Technologies projects have shown some very early progress (and the potential for progress in the near future) toward these metrics. Specifically:

- Advancement in battery storage technology increases the scope of using solar generation by potentially converting solar generation to a reserve resource.
- Standards developed through these projects can help improve the interconnection process.

8 Innovative Business Models

The adopted CSI RD&D Plan describes Business Development and Deployment projects as those "supporting the market and end-users." Within this category, the Plan also focuses on "activities that enhance the competitiveness of new technologies, or help reach a 'tipping point' into widespread commercialization." This can include projects that involve testing of technologies or measures that enable streamlining of regulatory processes or standards in ways that allow new products to come to market more quickly and at lower costs.

The *Innovative Business Models* projects had limited success, with several projects not meeting their stated objectives. The project outputs for this group also tended to have lower penetration with targeted audiences and less potential to develop clear market applications.

Specific categories of Business Development and Deployment activities identified in the Plan for possible grant funding include:

- Projects where "potential roles for utilities in solar PV, including attractive business models, are identified and vetted with utility companies;"
- Projects involving "lower cost, utility grade PV system control, metering, and monitoring capacity developed consistent with *(the)* 1% cost parameter established by the California Public Utilities Commission (Commission) for CSI;"
- Projects that "perform field tests to quantify operational risks and benefits of PV;" and
- Projects that "demonstrate improved PV economics using advanced metering, price responsive tariffs (e.g., Time of Use—TOU, Feed in Tariff), and storage."

The CSI RD&D Program identified Business Development and Deployment as a key focus area, where the Program could provide high value for grant funds. Business Development and Deployment was a primary focus in Solicitation 2 and a secondary focus in rounds 4 and 5. These program solicitations instructed applicants to engage in activities focused on the needs or areas of knowledge gaps detailed in Table 18.

Table 18: Business Development and Deployment Needs And Knowledge Gaps

Area of Need or Knowledge Gap	Description
Demonstrations of innovative ways to lower installation or operations and maintenance costs	Standardization of installation techniques or new approaches for warehousing of parts. Testing and demonstration of low-cost maintenance approaches and trade-offs between automated and manual approaches
Testing and demonstration of virtual net metering approaches	Projects that cut across different geographical/socio-economic strata in such a way that benefits and costs are demonstrated to be shared appropriately among users; and pinpoint significant issues necessary to expand the approach more broadly including but not limited to residential housing developments and the commercial arena and (by testing) help determine appropriate tariffs
Testing and assessment of economic aspects of PV using price responsive tariffs and storage	Projects that meter the energy use and delivery aspects of energy storage used in conjunction with solar systems; and test price responsive tariffs that provide appropriate pricing to higher value energy and can potentially be expanded to the commercial market place rapidly
Testing and demonstration of existing energy storage technologies capable of working with smaller solar systems and that allow the end user or utility to capture higher value from the energy produced (e.g., provide energy during peak).	Testing and evaluation of the economics associated with "unloading" of distribution feeders across more than just a peak hour of a peak day and taking into account capacity values used by utilities in determining feeder upgrades or expansion. Testing that quantifies the extent to which increasing the number of solar systems leads to "flow back"[13] on distribution feeders and the capital and operations and maintenance (O&M) costs incurred by utilities to prevent "flow back". Testing of solar system technologies developed to prevent "flow back" and how their costs compare to utility-based solutions.

A total of 10 of the 35 completed projects included a Business Development and Deployment component. Across the 10 projects, 12 discrete outputs were delivered that fall under the category of Innovative Business Models development and deployment. Table 19 presents a summary of the market needs identified in the program design, the projects that developed outputs that were designed to meet those needs, and examples of project activities.

[13] "Flow back" refers to the movement of electricity from the end user to the utility, which is different from the historically typical flow of electricity from the utility to the end user.

Table 19: Knowledge Gaps and Areas of Need and Corresponding Project Activities

Area of Need or Knowledge Gap	Project ID	Project Activity Examples
Demonstrations of innovative ways to lower installation or operations and maintenance costs	13, 16, 17, 23, 31. 37	• Business models and research for new products to lower installation costs and increase PV penetration. • Demonstrations and tools to lower installation and O&M costs of existing products. • Shared, collaborative, funding and procurement mechanism to lower installation costs.
Testing and demonstration of virtual net metering approaches	14	• Demonstration and recommendations for virtual net metering approaches
Testing and assessment of economic aspects of PV and storage using price responsive tariffs including with storage	12, 14, 15, 26	• Case studies of business strategies for optimal tariff decision making (e.g. peak load shifting, PV firming) • Analysis of pricing mechanisms to improve the cost and quality of frequency regulation • Business model development for construction, ownership and operation of community energy systems.
Testing and demonstration of energy storage technologies that allow capture of higher value from the energy produced	15, 26	• Testing and demonstration of financing mechanisms for PV and storage • Testing control strategies for energy storage to absorb renewable production variability

A summary of the 12 unique outputs from the Innovative Business Models projects is provided below in Table 20. Outputs include 11 hardware technologies covering Concentrated PV, storage, and hybrid PV technologies; five software platforms; and eight demonstration sites.

Table 20: Innovative Business Models Outputs by Project

Solicitation - Project ID	Output Type	Output Description
2 – 12	**Testing price responsive tariffs**	Optimize and manage DER dispatch schedules in real time; investigate changes in incentives and tariffs, to determine cost-effective strategies to support integration of high penetrations of solar. The project was delayed and did not meet its original objectives.
2 – 13	**Innovative ways to lower costs**	The goal of this project was development of a business model for deployment of a nascent PV technology, AC Plug-and-Play Solar PV Kits that can be installed by roofing contractors without an on-roof electrician. The project was successful. The actual test product is no longer in production but similar products are commercially available.
2 – 14	**Virtual net metering approaches**	Business models that incorporate virtual net metering for community level solar resources connected to single-family ZNE homes. The models were completed, benefits shown and policy recommendations made.
	Innovative ways to lower costs	Alternative business models for the construction, ownership and operations of the UC Davis West Village Energy Initiative system, especially as related to achieving Zero-Net-Energy (ZNE) for the single family homes for faculty and staff. Financial modeling and analysis was completed, however, real world implementation, which was planned, did not occur.
2 – 15	**Testing energy storage technologies to capture higher value**	The project identified and designed pre-commercial technology and demonstrated installation requirements, cost, permitting, and interconnection requirements. The project team designed a control platform that enabled remote control of energy storage devices. The project analyzed potential market mechanisms to reduce barriers and increase adoption and provides policy recommendations.
	Testing price responsive tariffs	Optimal rate designs and ISO Services for maximizing the value of combined PV and storage. Three studies were conducted that 1) investigated the effects of deployment of PV power on the grid and estimated economic impacts of PV, 2) identified pricing mechanisms to improve the cost and quality of frequency regulation, 3) analyzed strategic behavior between non-generating resources (NGRs) providing fast regulation in reserve markets.
2 – 16	**Innovative ways to lower costs**	Study to reduce costs of PV array installation by reducing design time through automation, reducing permitting time of projects, enabling optimized designs for smaller commercial rooftop systems, and decreasing on-roof time through factory manufacture of array wiring harnesses and matching combiner boxes. The project conducted seismic testing of arrays, created a suite of integrated design tools that reduces time to produce accurate, original PV array layouts, and developed document databases.

Solicitation - Project ID	Output Type	Output Description
2 – 17	**Innovative ways to lower costs**	Validated energy models and economic models to calculate the return on investment of Cogenra's cogeneration solar technology. The project validated energy models and developed an ROI tool that uses the energy models to provide financial information internally and to customers.
4 – 23	**Innovative ways to lower costs**	This project aimed to develop and implement an innovative financing mechanism for regional sustainability projects for municipalities, schools and public agencies to help reduce costs through seed funding, resources and training, and collaborative procurement. The funding mechanism, a revolving loan fund, and formation of an LLC was developed, and 37 public agencies engaged in the process, with 14 public partners signing MOUs to participate. Almost 150 sites were prescreened; 41 of those sites received full feasibility assessments; and 130 MW of viable solar projects were identified across all prescreened sites. 6.8MW of viable solar projects were included in a collaborative RFP representing 13 public agencies; 4 qualified vendors submitted bids on SEED Fund projects and 4.3 MW of solar were installed or are under contract. A second round of funding began in 2016.
4 – 26	**Testing price responsive tariffs**	A goal of this project was to develop tangible policy and planning recommendations for high penetration PV and energy storage dispatch and to develop tariffs and incentives, program designs and customer outreach strategies for behind-the-meter energy storage. A demonstration site of 34 homes containing Sunverge Solar Integration Systems (SIS) – a 2.25 kW PV system integrated with a 4.5kW/11.7 kWh battery – was established to test SMUD's DRMS to dispatch the SIS units, including over nine critical peak pricing events and eight test demand response. Based on the demonstration the project team developed models to analyze the costs and benefits of PV integrated storage from customer, regional and utility ratepayer perspectives and provided recommendations for program design.
5 – 31	**Innovative ways to lower costs**	This project was the second phase of Project 4 – 23.
5 – 37	**Innovative ways to lower costs**	The purpose of this project was to modify and enhance Clean Power Research's existing solar sustained vehicle (SSV) web service and develop an intuitive user interface to include integration of personalized driving and charging habits, separation of technology financing methods, and integration of smart meter (e.g., Green Button) data. These additions are aimed at adding value to detailed analytics and collated market statistics helping to drive action by end-users. The project was completed as planned.

Some of the Innovative Business Models research area projects struggled to meet their objectives for a variety of reasons. While there were some projects that struggled, there were also some notable strong successes. Below is a brief summary of projects that did not meet all objectives.

- **Project 2–12: Innovative Business Models, Rates and Incentives that Promote Integration of High Penetration PV with Real-Time Management of Customer Sited Distributed Energy Resources.** The original goal of this project included demonstration of optimization and dispatch strategies in real time, and development of a public cost benefit tool. Due to project delays including delayed availability of demonstration site data and lengthy software debugging and validation efforts, neither of these activities was completed.
- **Project 2–13: Low-Cost, Smart-Grid Ready Solar Re-Roof Product Enables Residential Solar Energy Efficiency Results.** This project met all stated objectives, and the project partners demonstrated and documented the potential for innovative business opportunities related to this technology. However, the specific product tested was discontinued by GE and is no longer available on the market. There are other similar products now available that could benefit from the findings of this project.
- **Project 2–14: West Village Energy Initiative: CSI RD&D Project.** The original goals of this project included developing viable business models for deployment of community scale solar, and then working with a third party investor to design, build, and operate a community scale solar resource at West Village. The project successfully developed and assessed business models; however, the construction of the housing development that would serve as the customer for the solar project was delayed. Therefore, the second part of the project did not move forward, and the business model could not be implemented.
- **Project 2–17: Improved Manufacturing and Innovative Business Models to Accelerate Commercialization in California of Hybrid Concentrating PV/Thermal Tri-Generation (CPV/T-3G) Technology.** This project met all stated objectives. Cogenra demonstrated the benefits of tri-generation technology, and the commercialized Cogenra product is installed at over 10 sites in California. However, SunPower has since acquired Cogenra, and this hybrid PV/T product has been discontinued. Despite this, some of the technology developed through the research project forms the basis of a new, lower cost panel line for SunPower.

Project outputs all have a development lifecycle that includes initial concept development, testing, and validation of performance in operational environments and industry adoption. Once adopted, the outputs should have effects on the adopting organizations and the industry more broadly, including lower generation costs, increased competition in the market, and clean jobs.

8.1.1 Innovative Business Models Short-Term Outcomes

Based on the nature of the Innovative Business Models projects, we identified particular areas of potential effects in our metrics from the logic model. Table 21 summarizes our assessment of the Innovative Business Models projects for each metric.

Table 21: Innovative Business Models Short-Term Outcomes – Metrics and Progress Assessment

Key Metric	Progress Assessment
# business models designed and tested, and validated	6
# models with documented adoption or likely to be adopted and # stakeholders adopting models	6
Stakeholders reached / attending demonstrations; percent of target audience reached	Low
Documented evidence that business models will support expansion of cost-effective solar	Medium
Performance of business model in operating environment documented	Medium
Reduced cost of solar projects; value of reduced stakeholder acquisition costs and/or reduced business risk	Medium
Increased customer awareness of solar projects; increase in sales growth	Medium

Number of business models designed and tested, and validated

The 12 Innovative Business Models outputs developed under the CSI RD&D Program projects reached different stages of development from theoretical design to testing and validation in a demonstration or operating environment. The evaluation team reviewed program documentation and results of in-depth interviews with grantees and market actors to categorize the development stage of outputs from each project, among three stages:

- Design only
- Design and testing either through simulation or demonstration
- Design, adoption, and validation in operating environment

Table 22 presents the stage of each output by project.

Table 22: Business Development and Deployment Output Stage

Solicitation - Project ID	Output Type	Development Stage
2 – 12	**Testing price responsive tariffs including with storage**	Design only
2 – 13	**Innovative ways to lower costs**	Design and Test
2 – 14	**Testing and demonstration of virtual net metering approaches**	Design Only
	Innovative ways to lower costs	Design Only
2 – 15	**Testing energy storage technologies to capture higher value**	Design, Adopt, Validate
	Testing price responsive tariffs including with storage	Design Only
2 – 16	**Innovative ways to lower costs**	Design, Adopt, Validate
2 – 17	**Innovative ways to lower costs**	Design, Adopt, Validate
3 – 23	**Innovative ways to lower costs**	Design, Adopt, Validate
4 – 26	**Testing price responsive tariffs including with storage**	Design and Test
5 – 31	**Innovative ways to lower costs**	Design, Adopt, Validate
5 – 37	**Innovative ways to lower costs**	Design, Adopt, Validate

Three projects (Projects 12, 14, 15) produced outputs that were in the design stage at the completion of the project. Project 12 designed and conducted very limited testing of three strategies of high penetration PV integration—peak load shifting, PV firming, and grid support—and provided recommendations for future studies and potential tariff or rate structures. Project 14 developed alternative business models for community solar projects and developed financial models to test and validate business model designs. Project 14 also provided recommendations for adoption of virtual net metering in single-family residential applications for community solar projects. Project 15 identified and designed utility retail and ISO wholesale rate structures, tariffs, and market mechanisms that could help bring combined PV and storage to new markets, and help optimize the value of these products.

Two projects included outputs that were designed and then tested in either a simulated or small demonstration environment. Project 13 developed a comprehensive business model design for "plug and play" ready-to-install PV system-kits including detailed market analysis, value proposition and business strategies, and market surveys, as well as a detailed best practices training program and financial options for residential solar PV and energy efficiency. These outputs were tested through market surveys and a small demonstration activity, and showed promise. Based on a 34-home demonstration site, Project 26 developed and analyzed highly detailed use case studies, including cost effectiveness and optimal rate design for a combined PV and storage technology. These studies provided important insights into the value of solar and storage systems to utilities and rate payers, in particular showing that the value of the systems is highly dependent on location and how the systems are operated and controlled.

Below are some additional details on the six Innovative Business Models projects that had their performance tested in operating environments.

- **Project 15: Advanced Grid-Interactive Distributed PV and Storage.** The primary goal of this project was to test a new energy storage technology, demonstrate strategies to integrate these technologies with existing solar assets and into the solar market, analyze the value streams that these systems could provide, and identify market mechanisms by which this value can be accessed. Key achievements included demonstration of net benefits to the grid and customers of the technology, technology developments and best practices that lowered the cost of installation, and development of important insights into product specification, code requirements and other aspects of the technology. Since the end of the project, the project partners have leveraged the findings of this grant to develop fully commercial products with hundreds of residential and commercial installations in California. One project partner stated that the project "*very clearly defined for us what is necessary for a battery system to be designed, owned and operated*" and ultimately was highly influential in the development of widely used commercial technology including software control platforms and storage technology.
- **Project 16: Reducing California PV Balance of System Costs by Automating Array Design, Engineering and Component Delivery.** This project aimed to reduce costs of PV array installation by reducing design time through automation, reducing permitting time of projects, enabling optimized designs for smaller commercial rooftop systems, and decreasing on-roof time through factory manufacture of array wiring harnesses and matching combiner boxes. The outputs of the project have been implemented by the project partners in their business operations in product development and design that has helped reduce balance of systems costs for the project partner. Findings from the project have also been operationalized in that they have been used to inform building code for unattached

solar arrays, and helped other market actors develop and refine products to reduce overall cost of solar installation.

- **Project 17: Improved Manufacturing and Innovative Business Models to Accelerate Commercialization in California of Hybrid Concentrating PV/Thermal Tri-Generation (CPV/T-3G) Technology.** This project validated energy models and developed a return-on-investment tool that uses the energy models to provide detailed and comprehensive project financials internally and to customers. These outputs were used by Cogenra to demonstrate the financial viability of its products. The company has since been acquired by SunPower, and the products have been discontinued.
- **Project 23 / Project 31: Solar Energy & Economic Development Fund (SEED Fund).** This project developed and implemented an innovative financing mechanism and collaborative project identification and procurement model for regional sustainability projects for municipalities, schools, and public agencies. The goal of this project is to help reduce costs through seed funding, resources and training, no-cost solar assessments, and collaborative procurement. Two rounds of funding have occurred across two grants. The project was moderately successful and achieved the performance goals set forth in the grant proposal. A second round of funding began in 2016.
- **Project 37: Innovative Business Models, Rates and Incentives that Promote Integration of High Penetration PV with Real-Time Management of Customer Sited Distributed Energy Resources.** This project modified and enhanced Clean Power Research's existing solar sustained vehicle (SSV) web service and developed an intuitive user interface to integrate driving and charging habits, financing methods, and smart meter data. The end product, WattPlan, was operationalized, and California ratepayers can access the PV+EV calculator and enter specific information about themselves and get information that can help them make decisions about purchasing and installing PV systems and purchasing electric vehicles. The PV+EV calculator developed for CSI was launched on September 23, 2015 and was freely available to ratepayers for one year. It is included as part of WattPlan, which is used by several California utilities. Clean Power Research continues to expand and enhance its software offerings, and the knowledge and insights gained from this project have influenced its software offerings.

Evidence of models with documented adoption or likely to be adopted and # stakeholders adopting models outside project

Aside from two projects (Projects 16 and 37), there is little evidence of adoption or awareness of project outputs beyond the project partners. Below is a description of the documented adoptions for Projects 16 and 37.

- **Project 2–16: Reducing California PV Balance of System Costs by Automating Array Design, Engineering and Component Delivery.** Outputs of this project have been adopted outside the project in two areas. First**,** the outputs have provided basic data and analysis essential for improvements in building codes that have led to improvements made by the ASCE 7 committee on seismic testing of building components in building codes. Secondly, roadmaps provided by the project can help facilitate the process for other solar companies in the state. One project partner noted that while he could not provide explicit information on other companies using the outputs, he was aware that other manufacturers were using their work to improve their systems resulting in cheaper and easier installation.
- **Project 2–37: Distributed Solar and Plug-In Electric Vehicles (PEV): Development and Delivery of an Interactive Software Platform that Provides Actionable Insights Regarding Solar Acquisition.** Outputs of this project have been widely adopted by CPR utility customers, as well as ratepayers. The software was available to California IOU customers for one year ending in September of 2016 and has seen very widespread use with over 10,000 customers using the tool within the first three months of it being available.[14] All three IOUs as well as SMUD and other utilities in California and nationwide are continuing to offer Wattplan to their customers.

In addition to these two projects, Projects 23 and 31, the Solar Energy and Economic Development fund saw some strong engagement with municipalities. Similar organizations or schemes have developed such as RE-volv, but there is no evidence that this project influenced those schemes.[15] Beyond these projects, there was little adoption or evidence of project awareness outside the project teams. Stakeholders we interviewed did not raise Innovative Business Models projects as projects of which they were aware. One stakeholder who was involved in CSI Program implementation noted that prior to being interviewed as part of the evaluation, he was not aware of the Innovative Business Models projects, but having reviewed the documentation, noted that the

> "*Business Models work is pretty well aligned with what my organization does generally and what I do specifically. I looked at the (CSI RD&D) website having been prompted by this interview, I went and looked and found some stuff that would have been important for our work that I wasn't aware of*".

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[14] WattPlan Revealing Savings of Electric Vehicles and Solar in California, New York, Arizona. http://www.cleanpower.com/resources/pr-wattplan-reveals-electric-vehicles-and-solar-savings/

[15] RE-volv is a 501(c)(3) nonprofit organization with a mission to help communities to invest collectively in renewable energy.

This interviewee was particularly interested in projects related to electric vehicles and virtual net metering strategies.

Documented evidence that business models will support expansion of cost-effective solar

Across the 10 Innovative Business Models projects, there is a varying degree of evidence that the outputs will support the expansion of cost-effective solar. Because the outputs of each project are different, we assess the level of evidence for each project individually:

- **Project 2–12: No evidence that business models will support expansion of cost-effective solar.**
- **Project 2–13: Limited evidence that business models will support expansion of cost-effective solar.** Market research conducted as part of the project indicated that the Grid-Ready Plug-and-Play PV kits can provide a valuable addition to the PV market, based on their performance and relatively low cost, estimated to be $3.99/W installed. In addition, the AC-module design provides the opportunity to open a new sales channel in the retrofit market via roofing contractors. Because the specific product has been discontinued, there is little ongoing work on this technology, with one stakeholder saying that they

  > *"are not aware of any significant development of AC systems but the market seems to be going in the other direction if anything, which is driving everyone to DC. But I think I still stand by my statement that there is a lot of benefit from an AC PV system in the retrofit market".*

- **Project 2–14: Limited evidence that business models will support expansion of cost-effective solar.** The project evaluated various business models to determine an "optimal" model that would allow for the deployment of community scale solar. While the evaluations were not achieved in an operational setting, there was some evidence that innovative business models could help achieve ZNE homes with community scale solar for close to the cost of traditional housing. A stakeholder in the project explained that although the project did not complete all its objectives, it

  > *"laid all that groundwork and did a deep dive when we did the grant; it will make it much more likely that we will be able to achieve it as we actually build the single family development going forward"*

  According to this stakeholder, the project also helped answer the question

  > *"how do we allow for this deep penetration of community distributed solar without breaking the backs of the IOUs because their business model wouldn't allow for it … and I think the CSI program is very valuable to continuing to explore that".*

- **Project 2–15: Strong evidence that business models will support expansion of cost-effective solar.** As part of the project, the project team conducted consumer research and investigated finance options for combined PV and battery storage systems. The project found that a combination of PV and grid interactive storage can achieve substantial cost savings for utilities and end customers, and a key to unlocking the benefits is overcoming the barriers to adoption including upfront costs. The project suggests that similar innovative finance mechanisms that have enabled recent growth in the distributed solar PV industry may help growth in deployments of distributed energy storage systems. Since the project completion, the project partners have experienced high uptake of their products indicating that their business models can help support expansion of cost-effective solar solutions. However, we can only make this case for the project partners specifically, not for the wider market.
- **Project 2–16: Strong evidence that business models will support expansion of cost-effective solar.** This project aimed to reduce costs of PV array installation by reducing design time through automation, reducing permitting time of projects, enabling optimized designs for smaller commercial rooftop systems, and decreasing on-roof time through factory manufacture of array wiring harnesses and matching combiner boxes. A major component of up-front solar costs are these balance of system costs, which the DOE estimates at 64 percent of total solar costs.[16] The design automation tools and research contributing to building codes in this project have already or will lead to decreased installation costs, which reduces upfront cost of solar systems supporting the expansion of cost effective solar.
- **Project 2–17: Limited evidence that business models will support expansion of cost-effective solar.** This project demonstrated a business model and emerging technology that presents a financially viable cogeneration solar system. These findings are specific to this technology. Cogenra was acquired by SunPower, and the product has been discontinued. However, some research from this technology is being applied as part of a new lower cost product from SunPower. Given this, we cannot say there is strong evidence that the business model-related outputs of this project will have significant impact.
- **Project 3–23 / Project 5–31: Strong evidence that business models will support expansion of cost-effective solar.** These projects have supported the installation and expansion of cost-effective solar through collaborative project identification and procurement and financing. Two rounds of funding have occurred across two grants. The project engaged 37 Marin, Napa, and Sonoma County public agencies in

[16] U.S. DOE. 2016. "Soft Costs 101: The Key to Achieving Cheaper Solar Energy". https://energy.gov/eere/articles/soft-costs-101-key-achieving-cheaper-solar-energy

the collaborative procurement process, and included 143 high-level site assessments and 41 full feasibility studies. The site-screening process identified potential for over 130 MW of solar power installation, including several sites with the potential for utility-scale PV installations. Twenty-five sites across 12 public agencies have entered, or are planning to enter, into purchase or power purchase agreement (PPA) contracts with the selected vendor with a combined total of approximately 5 MW capacity. The fund is being replenished, and a second round of projects was initiated in 2015; according to a project partner, SEI and Optony are engaging jurisdictions for a third round of projects which will result in at least 12 MW of installed solar.

- **Project 2–26: Limited evidence that business models will support expansion of cost-effective solar.**
- **Project 5–37: Strong evidence that business models will support expansion of cost-effective solar.** This project's output has seen high adoption by utility customers seeking to purchase PV systems or electric vehicles. While this product is relatively new, the project partners and stakeholders suggest that there is some evidence of increased adoption of solar. One key finding from this project was that 75 percent of surveyed customers indicated that they would rather get information about solar equipment or electric vehicles from the utility and would trust them more than contractors.

Reduced cost of solar projects; value of reduced stakeholder acquisition costs and/or reduced business risk

Similar to previous metrics, there is limited evidence that the business development and deployment projects have led to reduced costs of solar projects or reduced risk, and it is difficult to quantify the value of any reduced costs that have been realized. As noted previously, there are six outputs that have been adopted in some form, so we focus on these six projects to identify evidence of reduced cost or business risk associated with the projects.

- **Project 2–15: Strong evidence that business models will support reduced cost of solar projects and increase value of solar PV for customers and utilities.** This project suggested similar business models and financing that enabled adoption and deployment of PV be applied to solar storage. Specifically, SolarCity adopted a zero-down, cash-flow positive finance mechanism as the business model for PV product installation, directing private sector tax equity investments toward financing PV system installations, that allow customers to benefit from PV for no upfront cost, with an accompanying monthly finance payment that may be lower than their offset utility bill. This helps negate what is regularly seen as the key barrier to deployment of solar PV—a high upfront cost. In addition, third party ownership models, such as solar leases and power purchase agreements (PPAs), allow households who cannot afford to own a PV system to go solar. SolarCity adopted a similar model for combined PV and storage using Tesla's Powerwall product, and with the merger of Tesla and SolarCity, these products are now combined. This structure reduces the upfront cost of these technologies to customers. Battery storage integration provides risk mitigation for homeowners. There is also strong evidence that in theory the combination of PV and grid interactive storage can achieve substantial cost savings for utilities by decreasing reliance on other energy sources, and provision of backup power for an energy user with the potential to shift time of use energy and demand charges.

- **Project 2–16: Strong evidence that business models will support reduced cost of solar projects and increase value of solar PV for customers and utilities.** This project aimed to reduce costs of PV array installation by reducing design time through automation, reducing permitting time of projects, enabling optimized designs for smaller commercial rooftop systems, and decreasing on-roof time through factory manufacture of array wiring harnesses and matching combiner boxes. While we cannot assess the actual impact on array costs of this specific project, one stakeholder noted that the work from this project was "available to any manufacturer to use, so systems in California became cheaper and easier to install based on their work".
- **Project 2–17: Limited evidence that business models will support reduced cost of solar projects and increase value of solar PV for customers and utilities.** This project demonstrated a business model and emerging technology that presents a financially viable cogeneration solar system. According to project documentation, the project led to a 50 percent reduction in materials, installation, and operational cost of the Cogenra product. The product was installed at 20 other sites after this project; however, Cogenra was acquired by SunPower and the product has been discontinued. However, some research from this technology is being applied as part of a new lower cost product from SunPower. Given this, we cannot say there is strong evidence that the business model-related outputs of this project will have significant impact.
- **Project 3–23 / Project 5–31: Strong evidence that business models will reduce cost of solar projects and increase value of solar PV for municipalities and utilities, and have positive benefits for residents and businesses.** As noted, these projects have supported the installation and expansion of cost-effective solar through collaborative project identification and procurement and financing. According to project partners, the project has documented evidence that the SEED fund and assistance can reduce administration costs for jurisdictions by up to 75 percent and reduce procurement costs of solar technology by 10-12 percent due to reaching economies of scale through collaborative procurement. In total, the project team estimated a total installed cost reduction of 10 percent for jurisdictions. These

savings, as well as ongoing savings or payment for generation, accrue to the jurisdiction general funds, improving their overall bottom line which has broad benefits for jurisdictions and their residents.

- **Project 5–37: Limited evidence that business models will support reduced cost of solar projects and increase value of solar PV for customers and utilities.** While there is not strong evidence that this project and the resulting software would reduce costs of solar or EVs for customers, the goal of the project is to improve the value of solar and EVs for customers by providing customers with accurate data and recommendations.

Increased customer awareness of solar projects; increase in sales growth

There is very limited evidence that the business development and deployment projects have led to increased customer awareness of solar projects or increases in sales growth of products. Of the six outputs that have been adopted in some form, two are likely to have increased customer awareness and increased sales growth, and one is likely to have contributed to increased sales growth. The remaining three have little evidence of effect.

- **Project 2–15: Evidence of product specific sales growth and customer awareness, although uncertain if this has or will lead to broader industry sales growth or customer awareness of solar PV and storage.** The product developed in this project has gone on to have strong and self-sustained penetration in the solar market. SolarCity and Tesla have adopted the business models developed as part of this project, which took the lessons from PV financing and applied them to create a finance program for distributed storage installations. The success of the product and increased sales growth suggest that the business models developed in this project may have contributed to this success, but to what extent is not possible to determine. In addition, based on our research and interviews with stakeholders and project partners, it is not possible to determine if there is spillover from this research to the broader market that has increased sales or customer awareness for other similar products.
- **Project 5–37: Evidence of product specific sales growth and customer awareness, although uncertain if this has or will lead to broader industry sales growth or customer awareness of solar PV and storage.** Research from this project helped develop the WattPlan software platform that allows utility customers to analyze potential savings from electric vehicles, rooftop solar systems, or both, to assist with purchase decisions. Furthermore, the research indicated that provision of this software through utility platforms and branding increases customer confidence in results and likelihood of adoption. There has been a high level of utility customer use of the platform in California, which likely has led to increased sales of EVs and solar systems, as well as raised awareness of these products among utility customers.

- **Project 2–16: Limited evidence that business models will support sales growth cost of solar projects.** This project aimed to reduce costs of PV array installation by reducing design time through automation, reducing permitting time of projects, enabling optimized designs for smaller commercial rooftop systems, and decreasing on-roof time through factory manufacture of array wiring harnesses and matching combiner boxes. Upfront cost of solar projects is regularly cited as the primary barrier to adoption. As costs decrease due to the influence of this project, there is likely to be associated sales growth, but the magnitude of this growth is not possible to determine.

8.1.2 Innovative Business Models Medium-Term Outcomes

Medium-term outcomes refer to results or effects of project outputs on the market that are expected to occur after five years based on the program logic model. We primarily rely on qualitative metrics that are informed by project personnel and stakeholders to identify and assess second order outcomes from the program projects.

Table 23: Innovative Business Models Medium-Term Outcomes – Metrics and Progress Assessment

Key Metric	Progress Assessment
Documented (or predicted) changes to grid-connected distributed generation solar market (supply, demand, market infrastructure)	Low
Predicted influence on expansion of PV market opportunities	Low
Likelihood of easier financing of solar projects	Low
Potential for reduction in balance of system costs	Low

Documented (or predicted) changes to grid-connected distributed generation solar market (supply, demand, market infrastructure)

As discussed previously, across the 10 Innovative Business Models projects, there were varying levels of immediate project success. At least two projects resulted in business model outputs that have already impacted the solar market. The first of these projects provided a business model and financing approach for combined solar storage and solar PV that has pushed sales of a particular product from SolarCity and Tesla, leading to both increased supply and increased demand for this product (Project 15). The business model and financing approach was based on SolarCity's successful models for Solar PV including loan programs and power purchase agreements. If similar success is seen with solar storage products, which appears to be occurring given the general success of the product, it is possible the project will impact the overall market structure. The second project, Project 16, developed automated design approaches, and recommendations for permitting and building codes, that are likely to positively impact the overall cost of solar arrays. Reduced costs resulting from these innovations should increase overall demand for solar PV.

Across the remaining projects, there is limited evidence of direct impacts on long-term supply and demand or changes to the market infrastructure. Projects 37, 23, and 31 could have indirect impact on long-term market structure through increasing demand for solar products among utility customers and municipalities. Other projects that conducted research of rates and tariffs could also contain valuable information that could impact the structure of the energy market, but there is little indication that the intended audience has adopted these outputs.

Predicted influence on expansion of PV market opportunities

There is limited evidence to allow us to determine the influence on expansion of PV market opportunities resulting from Innovative Business Models projects specifically. Interviewed stakeholders and experts did not feel like they could definitively predict influence based on these projects. The exception was Project 15, which several interviewees noted as being very successful at developing and promoting behind-the-meter storage. As we have already documented, sales of these products have been high, indicating that there is potential for expansion in this product area.

Potential for reduction in balance of system costs

There is limited evidence to allow us to determine the influence on reduced balance of system costs resulting from Innovative Business Models projects specifically. Again, interviewed stakeholders and experts were reluctant to predict influence based on these projects. The exception was Project 16, which several interviewees noted as impacting the cost of solar arrays.

9 Knowledge Benefits

The CSI RD&D Program was designed to produce benefits to the California solar market through expanding the knowledge base of the solar industry, including filling existing knowledge gaps to enable successful, wide-scale deployment of solar distributed technologies. Knowledge benefits produced by development of the knowledge base, however, are often not accounted for when communicating results of programs and the program value to stakeholders.

There were significant *Knowledge Benefits* achieved by the grantee research activities through contributions to the overall solar energy knowledge base. These knowledge benefits occurred across all project categories and reflect the most important outputs of the CSI RD&D Program.

As emphasized throughout this report, a comprehensive evaluation of any RD&D program must be structured to capture those impacts related specifically to research projects. Foremost among these is the RD&D contributions to the knowledge base. Having a theory-based evaluation plan that has knowledge base contributions incorporated into the logic model helps ensure that these critical program impacts are addressed in the evaluation research.

To explore the different types of knowledge benefits produced by the Program, we have organized the discussion in this section around several different types of related impacts:

- Relationship building
  - Team composition
  - Team working dynamics
  - Project partnerships
- Knowledge dissemination
  - Knowledge exchange activities
  - Efficacy and fit of exchange activities
  - Knowledge spillover and external interest
  - Influential knowledge disseminators
- Knowledge gaps filled and follow-on production
  - Knowledge gaps and application
  - Target audience and knowledge recipients
  - Intellectual property and intention to use
- Citation analysis
- Market actor awareness and perceptions

Positive activity in these areas provides solid evidence that knowledge benefits are being produced and disseminated in such a way that will help achieve the longer-term program goals.

The original goals of knowledge base development for the CSI RD&D Program are detailed in Table 24. Given the RD&D focus of the program, all projects produced some form of knowledge with associated benefits.

Table 24: Knowledge Base Development Goals

Area of Need	Description
1) Fill existing knowledge gaps in research areas	Identify and fill knowledge gaps in three primary research areas - Grid Integration, Solar Technologies, and Innovative Business Models - while ensuring knowledge produced is not duplicative and leverages existing knowledge where possible.
2) Engage in knowledge exchange activities that transfer knowledge effectively to appropriate audiences and enhance knowledge capacity among stakeholders as well as industry more broadly	Identify and require engagement in formal knowledge exchange activities to transfer knowledge to appropriate audiences. Required activities include, required interactions with partners, webinars, and reports. Encourage other non-required or informal knowledge transfer activities, such as writing academic papers and developing conference presentations to transfer knowledge to actors outside of project team occurred. Optimize the impact of the knowledge exchange activities through thoughtful planning and timing of outreach efforts at different stages of the project. Document the most effective activities for future R&D programs.
3) Develop new relationships and partnerships among industry actors to facilitate future innovation	Promote formation of project teams that include partners with unique, complimentary skills and knowledge, and reach and influence to disseminate knowledge effectively. Encourage creation of partnerships with key stakeholders outside the project teams to disseminate knowledge. Develop enduring partnerships and relationships that can help facilitate future innovation and transfer of knowledge.

Table 25 presents examples of project activities that helped meet the knowledge base development goals.

Table 25: Knowledge Benefits Areas of Need and Project Activities

Area of Need	Project Activity Examples
1) Fill existing knowledge gaps in research areas	Projects addressed knowledge gaps across 15 distinct categories - forecast modeling, solar design tools, improved PV technology, improved CPV technology, innovative business and financial models, gaps related to interconnection rules, electric vehicles, solar regulations, solar resource modeling, energy storage, transmission and distribution modeling, tariff and incentive design, risk mitigation of high penetration PV, utility planning tools, and zero net energy buildings and integrated demand side management. The knowledge gaps were addressed by projects across Grid Integration (12 projects), Solar Technologies (3 projects), Innovative Business Models (5 projects) and cross cutting projects (9 projects).
2) Engage in knowledge exchange activities	The Program's focus on knowledge transfer resulted in a diverse set of activities. High buy-in to Program goals among project personnel led to many more knowledge exchange activities beyond what was explicitly required. Required activities were kick-off webinars, interim reports and webinars, stakeholder engagement, and final webinars. Non-required activities varied by project and included conference presentations, academic papers, and participation in industry working groups.
3) Develop or enhance relationships and partnerships	Program projects brought together well-known and deeply experienced teams, most of whom were already active in the California solar and utility market, had been involved with publicly sponsored RD&D programs, and had existing relationships with other key solar actors in the State. Project partners also worked with the Program Manager and independently to engage external stakeholders. Over forty partnerships formed that persisted after project activities ceased.

The knowledge benefits impacts in each category were assessed through the network analysis completed as part of this evaluation. Grantee and sub-grantee interviews were a primary source of information for the knowledge benefits assessment, as was the analysis of the grantee project data that included a review of how the research results were disseminated and used by external parties.

The remainder of this section provides a summary discussion of these knowledge benefits, with an expanded discussion included in Appendix F.

9.1.1 Relationship Building

Team composition

Understanding the composition of the grantee teams is critical for assessing how well the grantee projects will be able to produce knowledge benefits that can be sustained once the initial project has ended. This includes examining the team size along with the reach and influence of the individual team members. Large, diverse teams that function well share know-how, and over the long term, there are more opportunities for knowledge to spill over in diverse applications throughout the market. While knowledge can be packaged and transferred, know-how is less transferrable. The experience and professional reach of team personnel affects how much know-how developed during the Program and then how much additional is absorbed and will be available in the future.

One aspect of team composition is diversity, and a diverse set of experiences will generally improve the overall competency of the team. Thus, we assessed the diversity and unique competencies of Program teams. A less intuitive but important factor is the degree to which partnerships include a mix of public and private actors. Private sector actors are essential to project success as they bring market insight and cutting-edge capabilities. Public organizations, however, play an essential part in ensuring mid- and long-term knowledge benefits. Public organizations tend to be much more stable over the long-term than private companies, and their underlying strategies tend both to be less volatile and more dedicated to open knowledge resources. The latter was true of many of the public research organizations in the Program.

Based on our review, it is readily apparent that the CSI RD&D Program brought together well-known and deeply experienced teams, most of whom were already active in the California solar and utility market, had been involved with publicly sponsored RD&D programs, and had existing relationships with other key solar actors in California.

By reviewing the individual project documents and interviewing grantees, we were able to gain a deeper understanding of the team characteristics. Grid Integration projects tended to be larger and more diverse than projects under the other three funding areas. Teams with Grid Integration and Solar Technologies projects had high representation of research organizations, like national labs and industry research groups. By contrast, no Innovative Business Models or Cross-cutting projects included research organizations among their ranks. Universities, software firms, and consulting firms were well represented across the Program.

Teams led by solar hardware or installation firms were more likely to include organizations from outside the solar and utility sectors, including builders and retail organizations. Trade organizations were not well represented in the Program, even though they tend to possess significant market and policy understanding and access to information distribution channels.

Descriptions of team experience in many cases went beyond expert competency. One subject described their team members as market leaders. This sentiment was expressed independently across numerous respondents. One way that teams differentiated their team organizations from the market was by including organizations that had developed first-of-kind products or methodologies. Several teams included academics who had recently proved concepts relevant to the project scope of work. Alternatively, some teams enlisted organizations that had developed hardware or software that are new to the market. For example, some teams included leading smart inverter companies, and others brought in firms that owned potentially useful proprietary software. In each case, the teams indicated that these rare competencies were paramount to the project success.

Based on our analysis, we believe that the typical team composition was near-optimal for facilitating long-term knowledge benefits across the program, particularly for the Grid Integration projects. Teams leveraged rare skills, strong market position, and operational know-how; and included a mix of private sector firms and public research organizations. The benefits of strong team composition were strengthened by collaborative working relationships, as discussed below.

Team working dynamics

Another important area for investigation was the working dynamics that occurred during project implementation. Nearly all respondents praised the Program Manager Itron for facilitating stakeholder and market actor relationships, and supporting a vibrant research culture. This, according to grantees, is unique for RD&D programs. Several subjects with prior RD&D program experience conveyed that the flexibility to work through project bottlenecks and respond to discoveries and obstacles during implementation improved their capacity to leverage team resources.

The majority of large and small teams described explicitly collaborative team dynamics. Among respondents who felt their team was collaborative, most described the collaborative aspects in terms of feedback. Teams routinely drew on competencies and know-how in other organizations. In particular, teams were better able to prepare for the applied stages of projects by consulting the experiences of other organizations across the team.

Respondents described intra-team communication as structured, and most indicated consistently frequent communication during the active stages of projects. Many teams had weekly calls, most had some sort of structured expectations for checking in. One respondent exemplified the overall tone regarding partner organizations, commenting,

> *"I treated it as though they were staff at [my firm] and it was an internal project".*

There were a handful of exceptions, mostly with Solar Technologies and Innovative Business Models projects. Respondents described the working dynamic as more siloed, with different organizations working on discrete tasks, with little sharing of information or providing feedback. Respondents did not cast this independent approach in a negative light, however, indicating that it was largely a consequence of very significant differences in the types of work assigned to each of the partners.

In general, a spirit of collaboration typified the project team dynamics. Working dynamics and robust team composition set the stage for strong knowledge and absorptive capacity benefits; the high number follow-on RD&D and applied partnerships are early evidence that the benefits will follow.

Project partnerships

During the actual CSI RD&D Program implementation period, over 40 partnerships formed that persisted after the initial project activities ended. Partnerships formed between team organizations, between team organizations and stakeholders, and between team members and market actors.

Grid Integration projects formed many more partnerships on average, nearly two partnerships per project. By contrast, Cross-cutting and Innovative Business Models projects produced closer to one partnership per every two projects. The greater number of partnerships per project for Grid Integration may be in part due to the larger average team size. In may also be due in part to the newness or acuteness of the issue during the period of Program implementation. Finally, we saw no indication that enduring partnerships formed out of the Solar Technologies area projects.

Most enduring partnerships formed by Grid Integration projects were with stakeholders or other utilities, continuing and extending work similar to that of the original project funded through the Program. Partnerships also formed between research organizations in the teams—for instance, national labs and EPRI—and other technical team members. Enduring Grid Integration partnerships tended to focus on demonstration or application as opposed to continued research and development.

Enduring partnerships stemming from the Cross-cutting area took two general forms; several were partnerships with project stakeholders or with team members, others were with industry partners who have existing supply chain access. Partnerships with team members tended to be extensions of partnerships that predated the Program.

Team organizations that formed enduring partnerships with other project partners comprised most new partnerships in the Innovative Business Models area. The nature of these partnerships generally centered on research and development and data sharing.

9.1.2 Knowledge Dissemination

Knowledge exchange activities

Teams engaged in a variety of knowledge exchange activities, some of which were generated by the teams and went beyond the requirements of the Program. These exchange activities typically fell into three categories: stakeholder engagement, reports, and webinars. Stakeholder engagement includes: sharing data with stakeholders, formal and informal meetings, direct or ongoing outreach to stakeholders, presentations of findings to stakeholders, and project review meetings with stakeholders. The reports and webinars categories include both interim and final reports and webinars.

Teams found value in engaging stakeholders for feedback and in disseminating project knowledge into the broader field. Each project team participated in multiple stakeholder engagement activities, but usually produced one report and held one webinar.

Interview respondents explained that—because the Program reports followed a structured, expansive format—there was little reason to complete more reports. Some grantees felt that the standardized reports were not user friendly enough to capture an audience. Developing the reports was a major time commitment for the teams, and a few grantees suggested that they could have done more research or engaged in more effective knowledge transfer with the time it took to produce the required Program reports.

The Program-required webinars had similar issues. Respondents indicated that the webinars required a huge time commitment, and many felt that the return on time spent was producing and delivering the webinar was not high. Although some appreciated the experiences, many felt that the audiences were too small and too poorly matched to their project.

Teams were given license to pursue a variety of other knowledge exchange activities. Presenting at conferences was the most common non-required activity, reported by 89 percent of the projects, with Innovative Business Models projects least likely to have a conference presentation. About half of the projects published findings in academic peer-reviewed journals or as white papers.

Direct outreach to the intended audience and to stakeholders was reported by about half of the project teams. Grantees described this outreach as "spreading the word," going on "a roadshow," and "web outreach," with one grantee specifying the use of LinkedIn, and "email blasts to registered users." In addition to the required webinars, 14 projects reported conducting additional webinars to share project findings, using webinar distribution channels outside of the Program.

Many projects (74%), created resources that are available to the public as a result of the CSI RD&D project research. Tools and software included open source algorithms that can be downloaded from websites, formal data sets that can be downloaded, a training video that demonstrates how to use a tool, and a handbook for distribution engineers working with PV assessment and modeling. Maps that can be downloaded included irradiance maps that took into account variable cloud cover and maps of the feeders to show what areas could accommodate higher penetration of distributed energy resources.

The non-required information exchange activities provided a way for the project teams to inform their intended audience of project developments, obtain feedback from stakeholders to guide project research, and to promote the tools and methodologies developed in these projects. Project teams in the Cross-cutting and Grid Integration funding areas reported presenting information about their projects at trade conferences specific to their research areas. Examples included the Energy Efficiency Building Coalition conference, Electric Vehicles Association (EVA), American Council for an Energy-Efficient Economy (ACEEE), and Institute of Electrical and Electronics Engineers (IEEE). Interviewees from four Grid Integration projects reported that a main purpose of talking about their CSI project with those outside the Program was to get feedback from stakeholders or the broader industry to help inform the project research. As one Grid Integration grantee stated,

> *"Getting that feedback from the industry along the way helps steer some things. When the broader industry provides some of that feedback and input, frankly, it helps to strengthen and bolster the research."*

One Cross-cutting project used these non-required knowledge dissemination activities to announce when the California version of the BEopt tool was available, and another let the public know when resources became available for download from their individual websites.

In total, there were 11 reported demonstration sites across all 35 projects. The Grid Integration funding area accounted for more than half of these demonstration sites, as five of those projects combined for a total of six sites. Examples of demonstration projects given in interviews includes demonstrations of battery packs, a showcase home for ZNE homes and their integrated technologies, a field demonstration of the Qado tool for modeling PV penetration, and a training facility for people to learn how to use the project outputs.

Efficacy and fit of knowledge exchange activities

Project teams did not view the knowledge exchange activities as equally effective. Webinars and conferences targeted at the intended audience were viewed as effective by more than half of the projects. By contrast, one-third of projects found the final reports an effective method of spreading information about their project findings. Interviewees discussed the effectiveness of these activities mostly by describing what they found as effective, while few commented on what activities were less effective.

Grantees who explicitly mentioned activities they found to be less effective at disseminating project findings focused on Program-required reports and webinars, as discussed above. The grantee who mentioned reports said that *"most people don't sit around and read those."* The other grantee was disappointed with the number of attendees at his webinar.

The presence of stakeholder engagement, webinars (primarily non-Program related), and conferences at the top of the effectiveness scale for respondents across the funding areas reinforces the importance of audience and time spent in preparation. Numerous respondents expressed sensitivity to the time it takes to reach the right audience. One contact pointed out that—given the very technical nature of the topics covered by the Program—teams needed to find key people in organizations (like utilities) that really dealt with the topic, as there was little value to others.

Knowledge spillover and external knowledge interest

The Program generated substantial interest from stakeholders and other outside actors. We inquired directly during interviews about occasions where requests for information came directly from stakeholders or market actors. Fifty-six percent of Grid Integration projects and 44 percent of Cross-cutting projects received direct interest in their work from utilities[17] or ISOs, more than the other funding areas. These market actor-to-team overtures came in the form of requests for data, or explanations of methodologies after research presentations. A few projects noted that they pointed these interested stakeholders to the GoSolarCalifornia website, where reports and other information were available. Two project teams even noted interest from outside the US, one from Italy and one from the Caribbean.

Innovative Business Models and Solar Technologies projects received interest from public agencies or municipalities, as well solar hardware or installation firms, and community-based organizations. Examples of solar hardware and installation firms include SolarCity and other manufacturers of inverters, batteries, and modules. The CEC as well as

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[17] Several respondents described "system planners and operators", which we included in the utility category.

standards and testing organizations each expressed interest in various Cross-cutting projects.

Influential knowledge disseminators

Many (but not all) grantees described individuals from team organizations or stakeholders as highly active and effective in disseminating project findings. These types of actors are referred to as knowledge disseminators. We found that all mentions of Itron as an influential knowledge disseminator were by project teams in Solicitation 1 (4 of 7 projects). Project team members conducted more knowledge dissemination in later solicitations.

Five projects called out the joint DOE/CEC High Penetration PV forum as one of the most valuable aspects of the Program. Project team members also made important contacts during occasions when the Program administrator arranged for meetings between different active Project teams. In fact, six project teams reported that a key way the Program helped with knowledge exchange was facilitating connections to other researchers and organizations within the Program.

Only two project teams identified a way that the program hindered knowledge exchange activities, both of which were in Solicitation 4 and in the Grid Integration Funding area. Their critiques related to the rules around how the project budget could be spent, which reportedly limited their ability to attend conferences. One said that he desired greater flexibility with how projects can spend dollars for things other than labor, like travel to conferences, and thought the documentation requirements were a bit excessive. The other reported being constrained by the deadline by which he had to use the grant funds. He desired more time after completing the research to disseminate the findings.

9.1.3 Assessment of Knowledge Gaps Filled and Follow-on Knowledge Production

At the outset of the Program, team proposals were evaluated in part based on the reasonableness of the case made that the project outputs would address one of the knowledge gaps identified in the resolution. The teams identified specific knowledge gaps that were specific, narrow, and tailored to their skillsets. We reviewed the original project proposals to get a sense of how subjects envisioned critical gaps in the market and how they planned to close them. During interviews, we asked grantees and sub grantees to retrospectively define the knowledge gap they had sought to close, their target audience, and the innovative project outputs that resulted from project activities. We also asked them to explain how they leveraged existing public and proprietary resources to complete their projects. We then explored how program participation directly affected the teams and outside actors, in terms of follow-on research and changes in firm, product, or market strategy.

In this section, we discuss how effectively the Program addressed the needs and knowledge gaps project teams targeted. In order to accelerate the California PV market, Program knowledge needed to do each of the following:

- Produce outputs that closed knowledge gaps;
- Develop outputs into deliverables suitable for the habits and expectations of the intended audience; and
- Identify, reach, and transfer Program knowledge to market actors

Knowledge gaps and application

Through our analysis of grantee interviews and program documents, we identified 15 distinct categories of knowledge gaps that project teams attempted to address through their research. Knowledge gaps related to forecast modeling and design tools were most prevalent. For projects in the Cross-cutting funding area, gaps related to improved PV technologies were most common. Grid Integration projects largely focused on gaps related to forecast modeling, design tools, Interconnection Rule 21, and solar resource modeling.

Knowledge gaps differed somewhat across the four Program funding areas, though many overlapped. A large number of the knowledge gaps addressed by projects in the Cross-cutting funding area centered around the intersection of technology integration (e.g., energy storage) and energy analysis and optimization. While there were common strands across several projects within this funding area, they varied in how and where in the value chain their outputs matter.

Knowledge gaps articulated by Innovative Business Models projects were the most eclectic, sharing little in common with other funding areas. Knowledge gaps ranged from advanced solar hardware that needed demonstration and commercialization, to procurement challenges at public agencies, to inadequate rate and tariff structures. In this area, knowledge gaps tended to focus much more on major market gaps, as opposed to the nuanced technical, skill, and process gaps evident in the other funding areas.

Generally, projects addressed multiple complementary knowledge gaps, which enabled the project scopes to evolve in tandem with the teams' understanding. Many subjects credited the program managers for working with them to revise the focus of projects in order to emphasize efforts that would be more likely to succeed, would have greater near-term impact, or would lead to more opportunities for follow-on knowledge creation after the Program. While the orientation of knowledge gaps guided Program activities, teams had flexibility during Program implementation to act strategically and pursue high-impact opportunities.

Additional detail on how specific projects address knowledge gaps is provided in the previous sections summarizing each funding area.

Target audience and knowledge recipients

Project teams identified a range of potential audiences for their research, including utilities and ISOs as the primary audience for most projects, followed by public-facing and commercial organizations. Regulators and standards and testing organizations were a primary audience for each funding area, except Cross-cutting. System planners were a significant focus for Grid Integration projects. Conversely, public organizations (such as academics, community-based organizations, and municipalities) and commercial organizations (especially consultants and program implementers) were a high priority for all funding areas, except for Grid Integration projects.

We found that knowledge recipients differed slightly from the intended audience. For example, while utilities and ISOs represented both a target audience and a primary knowledge recipient, national labs and research organizations were more likely to be targeted as knowledge recipients than targeted as audiences. Additionally, we found the volume of knowledge recipients was significantly higher for projects in the Solar Technologies funding area compared to other funding areas.

Multiple respondents described ongoing efforts by program administrator Itron to make connections and facilitate meetings among project teams and key market actors. Several respondents expressed appreciation for this role, suggesting they would not have been able to obtain such broad audiences were it not for Itron. Respondents also credited Itron's staff for having widespread connections through the California market and federal agencies, due to their significant experience working in state agencies.

Respondents also noted that Itron helped to facilitate joint workshops with the U.S. Department of Energy, as well as periodic meetings among the project teams. The required knowledge exchange activities also standardized the immediate knowledge recipients. Webinars and Program sources (i.e., reports and papers) were posted on the GoSolarCalifornia website, and announcements were made through an opt-in email list. These Program attributes help explain why projects across the funding areas shared many knowledge recipients, even though intended audiences varied.

To assess the extent to which projects successfully reached their intended audience, we drew upon interview data to compare the target audience for each project with the organizations who ended up receiving knowledge from the project. This brief analysis reinforces the role that program design played in determining the composition of Program knowledge recipients. Teams interacted directly with a large number of knowledge recipients who had not been identified as target audiences. This, however, does not necessarily indicate a mismatch between the target audiences and knowledge recipients. Projects were able to make connections with their target audiences in every funding area.

The over-representation of knowledge recipients who were not part of the target audiences is likely a consequence of the formalized Program knowledge exchange activities. A second factor we identified that may have contributed to non-targeted knowledge recipients derived from subject responses, suggesting they changed the scope of their research as they learned and gained expertise during Program implementation. Changes in the research scope would reasonably change the intended audiences.

Our analysis did uncover challenges that some projects had in connecting with certain target audiences. Two audiences in particular proved challenging: solar hardware and installation firms, and commercial organizations (for instance, builders, retail). The difficulty to connect with solar hardware and installation firms, in particular, is surprising, considering that several subcontractors were from this subsector, as were a few of the principal organizations.

Intellectual property and intention to use program knowledge

We asked grantees to explain any intellectual property strategy that developed around the Program outputs. Twenty-one respondents from 19 projects provided responses. Overall, six grantees indicated that they did not have an intellectual property strategy at all. An additional 11 grantees reported that all project-related results were open source. In these cases, respondents explained that the research effort was not developed in a manner that easily lends itself to an intellectual property strategy.

A few projects stand out as exceptions. Five grantees reported they developed intellectual property strategies to commercialize some of what they learned during the Program. The intellectual property strategies centered on patent application. Four of the five were Grid Integration projects, and the fifth was an Innovative Business Models project.

No respondent mentioned other explicit intellectual property strategies, such as trade secrets, copyrights, or joint partnerships. The teams submitted patents around specific components of their outputs. For instance, one indicated they filed patents around software control methodologies; another indicated that the project prime had some IP already in place prior to the project for some of the hardware components developed. One subject indicated there was some resistance from another project team member to give away testing and validation software due to proprietary information.

Intention to use: team and non-team

We reviewed program documents and asked grantees about their plans to apply the knowledge gained after the end of the project. Grantees from 16 teams reported that they would leverage Program knowledge with follow-on RD&D funding, primarily by the U.S. DOE and the CEC. Four grantees and sub-grantees interviewed provided details on the follow-on research funding amounts they received, with follow-on research funding totaling $5,722,500 and ranging from $90,000 to $13,000,000.

Although the CEC invested in follow-on projects, several individuals who participated in the Program indicated that they would not pursue additional RD&D funding from California. These firms are located outside of California and mentioned that the contractual obligations of the EPIC program—the successor to the CSI RD&D Program—were too onerous and resulted in greater uncertainty.

The Program has been effective in stimulating other forms of follow-on use, apart from RD&D funding. According to interviews with project grantees, two-thirds (66%) of projects resulted in some type of follow-on research. Grid Integration projects were more likely to result in follow-on research compared to projects in the Innovative Business Models and Solar Technologies projects funding areas.

Utilities and ISOs were the main external organizations that expressed interest in using project knowledge operationally after the Program. This included utilities within California and throughout the U.S. The Innovative Business Models and Solar Technologies projects had a more limited range of organizations that expressed interest in using project knowledge compared to projects in the Cross-cutting and Grid Integration funding areas. Apart from experiencing more overall outside interest, Grid Integration and Cross-cutting projects made inroads with regulators, and with standards and testing organizations.

Overall, both market actors internal and external to the Program expressed a significant degree of interest in leveraging their Program experience to conduct follow-on work. The diverse spectrum of external actors planning to or already using Program knowledge sets in motion several distinct trajectories into the market. For instance, the application of knowledge by technology developers addresses a different market niche than does application by grid management experts or standards and testing organizations. This benefit is especially true for knowledge produced by the Cross-cutting and Grid Integration funding areas.

Grid Integration team members are currently well positioned to leverage Program knowledge directly. Application of Program knowledge directly by project teams carries with it several implications for knowledge benefits. First, the team members have the benefit of direct experience and "learning by doing", thus improving the ease and cost of leveraging Program knowledge. Second, the project team members have diverse networks of partners and clients, who become likely beneficiaries and recipients of Program knowledge. Finally, research has begun to show that solar sector knowledge produced in

California by firms based in California or working in California localizes the benefits of innovation to the state. It is reasonable to assume that follow-on innovation from the Program by firms based, working, or demonstrating in California will lead to accumulation knowledge benefits over time.

9.1.4 Citation Analysis

In this section, we discuss evidence of knowledge receipt by analyzing citation of program outputs. The Program produced at least 153 original papers and reports, with more forthcoming from several projects. Teams developed interim and final reports in compliance with Program requirements, and many teams published additional journal articles or technical reports to highlight specific aspects or implications of their findings.

As one measure of the reach of Program knowledge, we analyzed the citation of project reports and papers. We collected data and examined the following:

- Number of citations per project reports and paper
- The venue where a Program source was cited
- The organization type of the citing author's affiliation
- The citation pattern over time

Details of our analysis in each of these areas are included in Appendix F, with a summary of our findings provided below.

Among the 153 papers and reports publicly released by Program teams, 26 have been cited at least one time as of the time we collected data during Fall 2016. The 26 Program sources have been cited 395 times to date; though a single Solicitation 1 Grid Integration project accounts for 315 citations (80%). This unique project had published four of its seven papers in *Solar Energy* (n = 3) and *Energy Policy* (n = 1). The papers published in these high impact journals reached a combined total of 303 citations. The project's three other papers, two published in less well-known journals and one Program report, reached a combined total of only 13 citations. This strongly suggests that publication in high impact venues increased visibility of findings and drove a signification citation. Further supporting this observation, across all cited Program sources, papers that were self-published or published by the Program only accounted for 11 percent of citations. It is worth noting, however, that team members from universities and national laboratories released a number of reports beyond what the Program required, and it is too early to determine the long-term impact of these sources. At this stage, it does seem that uptake of self-published and Program released sources is slower than publication in high-impact journals.

Most of the sources that have been cited were produced by projects in Solicitation 1. A few projects from Solicitation 3 and one project from Solicitation 2 have also been cited.

Program sources released in later solicitations likely have not yet had sufficient time to be cited, especially when considering the lag time associated with peer review.

It is notable that only one project outside the Grid Integration funding area has been cited. No projects from the Cross-cutting or Innovative Business Models areas have been cited. Solicitations 1 and 2 had multiple projects from each funding area. The lack of citation suggests that the knowledge produced by Grid Integration projects is more relevant to market actors who cite research in the course of their work.

9.1.5 Market Actor Awareness and Perceptions

As part of our assessment of knowledge benefits, we developed a market actor survey to collect additional perceptions on the potential impacts of the CSI RD&D Program.

The market actor survey was designed to address three project outcomes:

- Awareness of program and project outputs
- Awareness of new ideas
- Adoption of program knowledge

Market actor Program awareness

Overall, the majority of the market actors we surveyed (91%) across the variety of the organization types reported they were aware that the state of California has funded RD&D to stimulate the state's solar market. Figure 6 below shows that more than half of the market actors (56%) even knew about specific projects that were funded by the program, although there were some organization types that were less aware of specific projects than others, including utilities, manufacturers, and installation contractors.

Figure 6: Awareness of the Program and Projects by Organization Type

Organization types	Aware of CSI RD&D program	Aware of CSI RD&D projects
Government (n=17)	100%	65%
Private research and consulting company (n=16)	94%	63%
University or nonprofit (n=15)	100%	67%
Utility (n=12)	92%	33%
Hardware manufacturer (n=11)	73%	36%
Installation contractor (n=9)	67%	44%
3P program implementer or software developer (n=8)	100%	75%
Total (n=88)	**91%**	**56%**

Perceived value of Program

To assess how these market actors perceive the value of the Program funded projects, we asked a set of questions about each of four actual projects that had completed their intended activities. Each project was presented with two pieces of information: 1) the particular barrier or challenges the California solar industry faced to which the project attempted to address, and 2) the project's outcome. Two projects fell under the Grid Integration focus area, and the other two projects fell under the Cross-cutting focus area as follows:

- Project 1: Development of optimal smart inverter setting (Grid Integration)
- Project 2: Software development for custom system design (Cross-cutting)
- Project 3: Understanding the effects of geographically dispersed PV system (Grid Integration)
- Project 4: Software development that optimizes energy efficiency, DR, storage with PV (Cross-cutting)

We presented one randomly selected set of two projects to each respondent—Project 1 and Project 2, or Project 3 and Project 4.

Figure 7 summarizes the responses to each of the four projects.

Figure 7: Perceived Value of Program by Project

	Project 1 (n=46) Grid integration	Project 2 (n=46) Cross cutting	Project 3 (n=42) Grid integration	Project 4 (n=42) Cross cutting
a) Project outcome "very relevant" to your organization's work	59%	30%	67%	60%
b) Project findings "very needed" for the CA solar market	67%	52%	74%	64%
c) "Very effective" in reducing knowledge gaps that exist in the CA solar market	57%	33%	50%	57%
d) "Very effective" in improving understanding and capacity of regulators, grid operators, and standard setters	50%	26%	74%	52%
e) "Very effective" in improving your organization's ability to provide services or develop products	33%	28%	36%	36%
f) "Very effective" in accelerating the integration of distiributed solar power into the CA grid	54%	39%	60%	55%

All of the above items were asked using 5-point scales with similar expression of degrees – for instance a) 'not at all relevant', 'a little relevant', 'somewhat relevant', 'very relevant', and 'extremely relevant'. The percentages show a combination of 'very' and 'extremely'.

Overall, the respondents reacted favorably to the outcomes of Project 1, 3, and 4, while slightly less so to Project 2. Across Projects 1, 3, and 4, more than half of the market actors thought that the project outcomes were 'very relevant' to their organizations (a) and about a third thought those projects 'very effectively' improved their organization's ability to provide services or develop products (e). Regarding these three projects, more than half of the market actors also thought the outcomes were 'very needed' for California's solar market (b), and 'very effective' in reducing knowledge gaps that exist in California's solar market (c). Additionally, more than half of the market actors thought these three projects were 'very effective' in increasing the capacity of regulators, grid operators, and other standard setters (d). As a whole, more than half of the market actors surveyed appraised that these projects' contribution to the acceleration of the solar power integration into the California grid was 'very effective' (f).

Although the perceived value of the Project 2 outcome was not as great as other projects, more than half of the market actors thought the project outcome as 'very needed' for the California solar market.

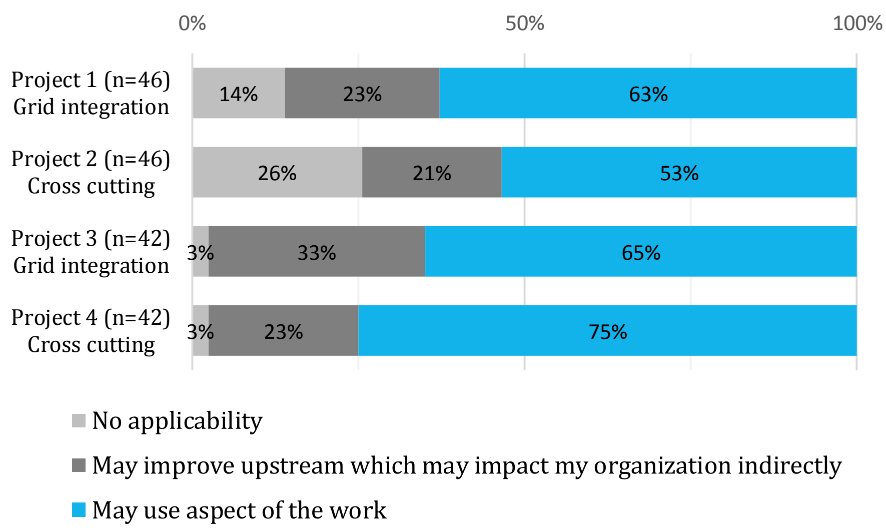
Generally, across the four projects, market actors who are engaged in research and development, grid operation and management, or third party services tended to hold higher opinions of the value of Program outputs. Contacts of hardware manufacturers were the least impacted group by these projects.

Intention and early indication of program knowledge use

Using the same four projects as concrete examples, we asked the market actors some questions that assessed the early indications that Program knowledge is being adopted.

Regarding all four projects, more than half of the market actors reported they are likely using Program outputs, findings, and tools for their organization's future work (Figure 8). The Project 4 outcomes in particular were viewed as directly relevant to their work. Even if they do not see these project outcomes to be directly useful to their work, about a quarter to a third of the market actors thought their work will indirectly benefit as these project outcomes influence the upstream. Overall, market actors thought Projects 3 and 4 produced the outcomes they are likely using.

Figure 8: Intention to Use Program Knowledge by Project



Of the market actors surveyed, 41 percent reported that their work has already used or benefitted from program outputs, clearly indicating early impacts of the program outside of the project teams (Figure 9). Contacts of government, university/nonprofit, and private research and consulting companies or those who are engaged in the research and development or policy analysis are the leading users of the Program outputs so far. Few of the hardware manufacturers have yet found ways to adopt the project knowledge.

Figure 9: Early Indication of Program Knowledge Use by Organization Type

Organization types	Have used or benefitted from CSI RD&D projects outcomes
Government (n=17)	53%
Private research and consulting company (n=16)	44%
University or nonprofit (n=15)	53%
Utility (n=12)	33%
Hardware manufacturer (n=11)	18%
Installation contractor (n=9)	33%
3P program implementer or software developer (n=8)	38%
Total (n=88)	**41%**

We also asked market actors who reported having used or benefited from Program outputs how their organizations have used the information (Figure 10). Most commonly, market actors reported Program outputs are used to educate their clients or audience, for their research and development activities or for improving their projects and services. Another use of the Program outputs reported was to apply for other research funding, for which a few of them have been awarded.

Figure 10: Ways Program Knowledge Used (n=36)

Ways CSI RD&D project information used	
Educating clients and audience	69%
Research and development	69%
Improving products and services	58%
Applying for funding	39%
Increasing sales or market	31%
Other	14%

9.1.6 Knowledge Benefits Summary

Follow-on applications of Program knowledge are already under way, and many of these include direct support from grant awardees. The presence of team members in follow-on use of Program knowledge accrues to the benefit of their partners and client networks. Follow-on projects include RD&D, client services, expansion of products and services, and use by outside partners. The high degree of evident follow-on uses of Program knowledge is in part due to the flexibility afforded to teams by the Program administrator, which worked with teams to revise research emphases as new information came to light. Teams felt this Program aspect was atypical for public RD&D programs, and helped match outputs with market needs.

Program design led to selection of teams committed to knowledge transfer. Most teams went beyond Program-required knowledge exchange activities, and many created knowledge spillover opportunities by releasing resources freely to the public and by developing demonstration sites. Teams identified direct stakeholder engagement, non-Program webinars, and conference presentations as the most effective knowledge exchange methods. Many projects relied on non-required knowledge exchange opportunities to reach key audiences.

The Program Manager Itron worked closely with teams to cultivate audiences for the research outputs, but some struggled to make the right connections. The time it took to produce Program-required webinars and reports was viewed by grantees to be incommensurate with effectiveness of knowledge transfer. As a consequence, some teams emphasized one-off and non-required knowledge exchange activities. Some teams noted that restrictions on how the Program could be used for knowledge exchange complicated pursuit of effective knowledge exchange activities.

Teams connected with knowledge recipients throughout the California market; however, many of the knowledge recipients for some projects did not align with the intended audiences the teams set out to reach. Teams praised Itron for facilitating stakeholder and market actor relationships, reducing the time spent for teams to reach key audiences. The mismatch between knowledge recipients and target audiences, however, appears to be due to the formalized Program knowledge exchange activities, which centralized a lot of Program outreach through the GoSolarCalifornia websites, the opt-in email list, and existing contacts of teams and the Program manager. Teams may have better reached their intended audiences with a more exact and individualized approach for market actor and stakeholder engagement, and for knowledge exchange efforts.

California market actors were familiar both with the Program and with specific projects. Market actors engaged in research and development, grid operation and management, and third-party electricity market services held the highest opinion of the value of Program outputs. Market actors are currently using Program outputs primarily to educate their clients, for their own research and development, and to improve products and services. Even market actors who do not see an immediate direct use for Program outputs in their own work viewed outputs as needed and likely to benefit them indirectly.

10 Conclusions and Recommendations

10.1 General Evaluation Conclusions

Overall, the CSI RD&D Program has been successful on multiple fronts. Feedback on program management by the grantees has been almost universally positive, with a few relatively minor suggestions for improvement. The Program also achieved significant progress on the short-term progress metrics identified in the logic model for most of the research areas. Note that while some individual grantee projects did not achieve their goals or ended early, this is not necessarily a poor reflection on the Program. Research programs that are truly pushing the envelope in terms of exploring new technologies will have some projects that fail. This is arguably better than a research program that chooses 'safer' projects that are less likely to fail, as these projects tend to involve technologies that are closer to commercialization and therefore in less need of research dollars to become viable in the market.

The overarching conclusions drawn from the evaluation are presented below. The conclusions are first discussed relative to the program management and then for each of the major project types discussed in the earlier report sections. Following this, a discussion is presented of how well the Program achieved the original goals the CPUC established for the CSI RD&D Program and this evaluation.

Overall Program Management

The feedback received on Itron's program management was very positive across multiple criteria. Specific accomplishments include the following:

- **The Program design was clearly communicated to relevant stakeholders and the Program was executed as designed.**
- **The Program Manager Itron performed very well and carried out all functions and duties of the Program Manager outlined in the CSI RD&D Adopted Plan.**
    - **The proposal solicitation and selection phases were completed with no complaints from participants.** All project grantees interviewed who participated in the proposal solicitation and selection phases expressed high satisfaction with the process, expressing that instructions were easy to understand and communication about the applications was clear and timely.
    - **The Program Manager effectively managed the grant agreement and contracting phases.** All grantees expressed satisfaction with the contracting process, explaining that it was professionally managed. Grantees from nine projects did note challenges with contracting, but all issues were resolved satisfactorily.

- Oversight of project implementation was excellent with all grantees and relevant stakeholders expressing high satisfaction with the process. Evidence suggests that Itron regularly monitored project progress and provided essential feedback and project coordination.
- **The Program Manager went above and beyond the formal role.** Many grantees and stakeholders detailed valuable project assistance beyond what was required under the contract, which directly led to more successful projects.

- **Program data were well maintained and available with all but one project completing all the required documentation.**
- **The Program Manager and CPUC staff communicated well with other research entities and agencies to reduce duplication of efforts** according to respondents from other research agencies (the California Energy Commission, the US Department of Energy, National Renewable Energy Laboratory, etc.)
- **Projects demonstrated strong adherence to key principles of the CSI RD&D Program.** The Program design incorporated adherence to the Program principles as a component of proposal scoring and selection. The design was successful and the evaluation found that projects aligned with the Program principles**:**
  - Improve the economics of solar technologies by reducing technology costs and increasing system performance – there is strong evidence that the Program led to reduced costs of some solar technologies and balance of system costs, as well as developed innovations that will have a positive impact on technology and grid performance.
  - Focus on issues that directly benefit California, and that may not be funded by others – the Program selected projects designed to produce outputs with direct benefits to California including innovations specific to the California climate, and designed for the California grid. Outputs of these projects have demonstrated benefits to California and the broader solar community. The Program adds to the pool of research conducted in California that is likely to attract innovators and businesses to the State.
  - Fill knowledge gaps to enable successful, wide-scale deployment of solar distributed generation technologies – the Program projects targeted specific, important knowledge gaps in the areas of Grid Integration, Solar Technologies, and Innovative Business Models. Stakeholders and experts agreed that many successful projects helped fill these gaps.
  - Overcome significant barriers to technology adoption – projects successfully focused on technology improvement, development and improvement of regulations and standards, and streamlined product development to reduce costs, all of which have reduced or are likely to reduce barriers to technology adoption.
  - Take advantage of California's wealth of data from past, current, and future installations to fulfill the above – projects successfully leveraged and in some

cases improved on a vast range of existing information including data sources, academic research, and the outputs of previous research and development efforts.
  - Provide bridge funding to help promising solar technologies transition from a pre-commercial state to full commercial viability – several projects took promising solar technology from a pre-commercial state to close to or actual full commercial viability including products from Tesla, SolarCity, General Electric, and Cogenra.
  - Support efforts to address the integration of distributed solar power into the grid in order to maximize its value to California ratepayers – several projects were highly successful in producing outputs that improve and advance the integration of distributed solar resources into the California grid, which have led to or are likely to lead to a more robust grid, improved energy security, and improved rates and tariffs which will benefit California ratepayers.

10.2 Research Area Conclusions

Grid Integration

Grid Integration was the most successful research area, with the vast majority (18 of 19) of the projects meeting all the original objectives and having findings widely disseminated to their relevant audiences.

Key accomplishments and evaluation conclusions for these projects relative to logic metrics and original Program goals include the following:

- **Grid integration projects produced highly valuable outputs that have seen high rates of adoption with 33 unique outputs being adopted across 19 projects.**
- **Grid integration project outputs have or will improve economics and enhance integration of high penetration PV.** Some key successes included:
  - **Research projects demonstrating the viability of high penetration PV on the California grid.** Several studies indicate that native limits of grid feeders can exceed the 15 percent limit set under CA Rule 21 and with advanced inverter controls and appropriate mitigation strategies, there is potential for very high penetration of PV.
  - **Planning and modeling tools for high-penetration PV** including enhanced insolation data, improved PV system modeling methodologies and tools to improve visibility of distributed solar resources to grid operators and planners, and new screening methodologies to efficiently evaluate new interconnection requests.
  - **Testing and development of hardware and software for high-penetration PV** including development of software visualization tools, enhancement of utility

software tools to incorporate enhanced simulation and forecasting methodologies, and lab and field testing of advanced PV inverter technology.
    - **Demonstration of enhanced solar modeling tools** including field validation of PV simulation and forecasting model methods and software, and integration of PV fleet simulation methodologies into utility software tools.
    - **Permanent demonstration sites addressing integration of energy efficiency, demand response and energy storage, and demonstrating best practices and modeling impacts of ZNE homes.**
    - **Analysis and research to inform grid integration rules and standards as well as to develop industry standards and protocols for solar technology and hardware.**

Each of these accomplishments is a demonstration of a positive impact of the Program that relates directly to the short-term logic model outcomes. This signifies that the Grid Integration projects are on the correct pathway for helping achieve the Program's longer-term goals.

The Delphi panel reviewed information on the Grid Integration projects and came to similar conclusions. Of all project areas reviewed, the Delphi panel gave the Grid Integration project area the highest ratings, and it was also the research area where there was the most agreement, with each reviewer rating each category either a 3 or 4 on a 0-4 scale. On a 0-4 scale, the panelists agreed that the selected projects had a significant impact in addressing the CPUC research needs (average rating = 3.75). Similarly, the panel agreed that the Grid Integration projects were likely to create ratepayer benefits (3.63), provide economic value to the grid (3.75), expand market opportunities/decrease barriers (3.88), and gain regulatory and institutional acceptance (3.75).

Solar Technologies

The Solar Technologies project group had varied success, with most projects meeting all project objectives but some projects either not meeting stated objectives or investing in technology that proved not to be viable in the market at present.

Examples of the varying success of these projects include the following:

- **Two projects conducted research into highly successful new technology.**
    - A project between SolarCity and Tesla demonstrating new battery technology and control systems led directly to development of the Tesla PowerWall product, which was predicted to have in excess of 168 MWh in sales this year ($44 million in revenue). The relationship between Tesla and SolarCity that developed during the project was a factor leading to Tesla acquiring SolarCity in 2016.

- A project by Sunlink involving seismic testing and design automation of solar mounting units. This led to:
    - Sunlink developing new software to improve design and reduce costs of mounting products.
    - A new startup company that has created automated design software.
    - Industry-wide improvements in mounting tech and cost reductions through knowledge transfer and influencing building codes.
- **Three concentrated photovoltaic (CPV) projects were successful, but the technology is not economically viable at this point.** A stated focus of the Program for Solar Technologies was to assist development of concentrated solar technologies, which at the time of the program design was a technology with the potential to compete with silicon solar PV. Three projects focused on concentrated PV technology and had successful outcomes. However, falling silicon prices have reduced the competitiveness of CPV, and most CPV companies have gone out of business. All three technologies are not actively being produced at present.
- **The remaining projects were either not successful in achieving their objectives (1 project), the investigated technology is no longer being produced (1 project), or the projects met their objectives but their success is not determinable given the short amount of time since project completion (5 projects).**

Despite these issues, the Solar Technologies projects typically had positive benefits for the project partners, and potentially for the overall penetration of distributed solar. It is not clear if the project outputs were accessed or leveraged outside of project teams, however. The combined effect was a somewhat limited achievement of the metrics identified in the logic model for this project pathway.

The Delphi panel had slightly lower ratings for the Solar Technologies group, and there was less agreement across panelists with the rating scores. On the 0-4 point scale, there was general agreement that the selected projects appeared to address the CPUC research needs for the Solar Technologies area (average rating = 3.5). The ratings were somewhat lower when the panel was asked to rate the likelihood of creating ratepayer benefits (3.25), providing economic value to the grid (3.25), and expanding market opportunities/ decreasing barriers (3.38). The lowest rating was given when assessing the likelihood that the Solar Technologies projects would gain regulatory and institutional acceptance (2.88).

Innovative Business Models

Of all the project groups, the Innovative Business Models projects had the least success, both in terms of achieving the stated project goals as well as in demonstrating short-term progress on key outcomes identified in the logic model. There were also issues with project knowledge having limited penetration with targeted audiences and lower potential to develop into concrete models with clear market application.

Examples of both the successes and challenges for this group included:

- **Two highly successful technology projects also developed business models and strategies that have proved successful** and have helped support expansion of cost-competitive solar technologies by reducing costs or increasing value of the solar and storage technology to owners and utilities by:
  - Lowering solar system installation or operating and maintenance (O&M) costs.
  - Testing and demonstrating the economic value of storage systems and developing financing models for these systems.
- **Two projects developed comprehensive business models and economic valuation tools for deployment of nascent PV technologies with the potential to help lower solar system installation and O&M costs; however, the products have been discontinued.**
- **Two projects worked to develop and implement a collaborative procurement and revolving loan program.** These projects met the stated goals, and the fund continues to function beyond the projects; however, the overall reach of the fund was not as broad as project partners and stakeholders had hoped.
- **Multiple projects conducted studies and analysis that was either inconclusive or has not found traction in the broader market**. Projects conducted analysis to test virtual net metering approaches, tariffs that reflect the time dependent value of energy storage to system owners and/or utilities, and economic value associated with solar systems. In several cases, these tests were incomplete or inconclusive. In some cases, projects produced potentially valuable results; however, there is little evidence of this knowledge reaching intended audiences.

The results of the Delphi panel also reflected the varied success of the Innovative Business Models project group, with lower ratings and less consensus on the ratings for each issue covered. In the follow up discussion with the panelists, part of the disparity of ratings was due to the fact that the Innovative Business Models category covered the widest range of project types. Additionally, this was also the category that was least consistent with more traditional RD&D topic areas. Despite this, the panelists did give a relatively high rating on whether the funded Innovative Business Models projects addressed the research needs identified by the CPUC (average rating = 3.25). It was less clear to the Delphi panel that the Innovative Business Models projects were likely to produce ratepayer benefits (3.0), provide economic value to the grid (3.0), or expand market opportunities/decrease barriers (2.5). The Innovative Business Models group also received the lowest ratings for gaining regulatory and institutional acceptance (2.67). In general, panelists mentioned that the lower ratings were due in part to limited evidence that the Innovative Business Models had much application or acceptance beyond the original project team.

Knowledge Benefits

The CSI RD&D Program was very successful in creating knowledge benefits, which may be the most important metric of success when evaluating a research program. Improving the knowledge base by producing a range of knowledge benefit outcomes was also the dominant feature of the program logic model. The success of the CSI RD&D Program in creating numerous knowledge benefits is an essential step toward achieving the longer-term program goals.

Specific knowledge benefit achievements included the following:

- **Team composition was near-optimal for long-term knowledge benefits across the Program, highest among Grid Integration projects**. Teams leveraged rare skills, strong market position, and operational know-how; and included a mix of private sector firms and public research organizations. The benefits of strong team composition were strengthened by collaborative working relationships.
- **Collaborative team dynamics were the norm across projects, leading to many follow-on collaborations, with more than 40 enduring partnerships stemming from the Program**. Partnerships formed among team organizations, between team organizations and stakeholders, and between team members and market actors. Working dynamics and robust team composition set the stage for strong knowledge and absorptive capacity benefits; the high number follow-on RD&D and applied partnerships are early evidence that the benefits will follow.
- **Many follow-on applications of Program knowledge are already under way, many of which include direct support from grant awardees**. The presence of team members in follow-on use of Program knowledge accrues to the benefit of their partners and client networks. Follow-on projects include RD&D, client services, expansion of products and services, and use by outside partners. The high degree of evident follow-on uses of Program knowledge is in part due to the flexibility afforded to teams by the Program administrator, which worked with teams to revise research emphases as new information came to light. Teams felt this Program aspect was atypical for public RD&D programs, and helped match outputs with market needs.
- **Program design led to selection of teams committed to knowledge transfer. Most teams went beyond Program-required knowledge exchange activities, and many created knowledge spillover opportunities by releasing resources freely to the public and by developing demonstration sites**. Teams identified direct stakeholder engagement, non-Program webinars, and conference presentations as the most effective knowledge exchange methods. Many projects relied on non-required knowledge exchange opportunities to reach key audiences.

- **The Program administrator worked closely with teams to cultivate audiences for their outputs, but some struggled to make the right connections**. The time it took to produce Program-required webinars and reports was viewed to be incommensurate with effectiveness of knowledge transfer by some project teams. Thus, teams emphasized one-off and non-required knowledge exchange activities. Some teams noted that restrictions on how the Program could be used for knowledge exchange complicated pursuit of effective knowledge exchange activities.
- **Teams connected with knowledge recipients throughout the California market; however, many of the knowledge recipients for some projects did not align with the intended audiences the teams set out to reach**. Teams praised the Program administrator for facilitating stakeholder and market actor relationships, reducing the time spent for teams to reach key audiences. The mismatch between knowledge recipients and target audiences, however, appears to be due to the formalized Program knowledge exchange activities, which centralized a lot of Program outreach through the GoSolarCalifornia websites, the opt-in email list, and existing contacts of teams and the Program Manager. Teams may have better reached their intended audiences with a more exact and individualized approach for market actor and stakeholder engagement, and for knowledge exchange efforts.
- **California market actors were familiar both with the Program and with specific projects**. Market actors who were engaged in research and development, grid operation and management, and third-party electricity market services held the highest opinion of the value of Program outputs. Market actors are currently using Program outputs primarily to educate their clients, for their own research and development, and to improve products and services. Even market actors who do not see an immediate direct use for Program outputs in their own work viewed outputs as beneficial to the California market and ratepayers as a whole.

10.3 Performance Relative to Evaluation Goals

The CPUC established several overarching research goals for this evaluation, and our assessment of the Program performance relative to each of these goals is summarized below.

Size of grant obtained from CSI RD&D funds

The CSI RD&D Adopted Plan established guidelines for the recommended allocation of funding across three RD&D target areas. As shown in Table 26, the Program adhered to these recommendations, with actual funding amounts close to the original targets for each research area.[18]

Table 26: Funding by Research Area

Target Activity	Goal %	Actual Funding	Actual %
Grid Integration	**50-65%**	$17,947,659	51%
Solar Technologies	**10-25%**	$5,883,459	47%
Innovative Business Models	**10-20%**	$7,424,801	42%
Total		**$31,255,919**	**49%**

Leverage from other funding sources (use of match funds)

The CSI RD&D Adopted Plan identified cost sharing as an important factor in project selection and a key evaluation criterion in part because it encourages project discipline. The CSI RD&D Adopted Plan guided the Program to follow the principle that the closer a project is to commercialization, the higher its cost share requirement. In other words, cost share requirements for development projects would be low, around 10 percent, while projects reaching the demonstration and deployment phases would be required to provide a 50-75 percent cost share—a target that is fairly consistent with DOE and other funding agency requirements.

The amount of total funding and cost sharing is summarized in Table 27. Itron and the proposal selection teams were careful to consider cost sharing as a key component of project selection. Overall, across the three research areas, the Program saw approximately 50 percent cost-sharing in aggregate as shown in the table below. Cost sharing was lower for Innovative Business Models and Solar Technologies projects and higher for Grid Integration projects, which aligns with the principle outlined above. The lowest project cost share was 20 percent and the highest was 65 percent.

Table 27: Funding and Cost Share Summary

Target Activity	CSI Funding	Match Funding	Total Funding	Cost Share %
Grid Integration	$17,947,659	$19,045,785	$36,993,444	51%
Solar Technologies	$5,883,459	$5,274,662	$11,158,121	47%
Innovative Business Models	$7,424,801	$5,460,071	$12,884,872	42%

[18] In these calculations, we use the primary research area for each project. There were nine Cross-cutting projects that conducted activities across research areas. If funds are allocated evenly across research areas for these projects, the allocations are: Grid Integration = 53%; Solar Technologies = 23%; Innovative Business Models = 24%.

Total	**$31,255,919**	**$29,780,518**	**$61,036,437**	**49%**

Benefits for California ratepayers

An important overarching goal of the CSI Program is to provide benefits to California ratepayers, and in this area, the Program had a significant positive impact. All projects had the majority of their activities conducted in California (in most cases, all activities were conducted solely in California), and all projects involved at least one major project partner or sponsor based in California. Likewise, projects were selected that targeted issues or barriers that particularly affect California.

The project outputs activities are also on a path that is consistent with providing longer-term ratepayer benefits in the future, as identified through the program logic model. Important benefits that have accrued or are likely to accrue to California ratepayers include:

- **Increased penetration of solar generation resources included distributed solar PV leading to cleaner energy generation, avoided energy generation costs, increased grid resiliency, environmental benefits, and economic benefits:**
  - The CSI RD&D Program projects directly led to installation of approximately 5.2 MW of installed generation in California with 5 MW coming from projects funded through one project.
  - Several projects contributed to a significant level of installed solar generation and storage in California after completion of the project including:
    - Installation of Tesla/SolarCity storage and PV technology that led to installation of 350 units of combined PV and battery storage units in the year after the project. This technology then led directly into the PowerWall and PowerWall 2.0 products from Tesla that have been available for sale since the beginning of 2015, with Tesla expected to sell 168.5 megawatt-hours of energy storage systems to SolarCity in 2016, up from 25.8 megawatt-hours in 2015. This represents a revenue increase from $8 million to $44 million.
    - The Cogenra SunPack product was installed at approximately 20 sites after the project. Sunpower acquired Cogenra in 2015 and discontinued the SunPack product. Technology developed through SunPack development is used in SunPower products including their Performance line of products.
    - Other companies including SunPower and Sunlink have developed products from the CSI RD&D Program project that have seen high market adoption.
- **Improved electric grid reliability with higher penetrations of solar and other renewable resources**. Grid Integration projects were successful in developing important outputs such as improved solar data, forecasting models, simulation tools, and risk mitigation strategies that have or are likely to:

- Improve visibility of solar generation for system operators.
  - Enhance the ability of system planners to optimize the value to the grid and ratepayers of new solar installations.
  - Reduce the risk of negative impacts on the California electricity grid from high penetration levels of solar generation resources.
  - Improve overall system reliability through reduced unintentional islanding, inverter trips, voltage variation, and other common issues that can arise from high penetration PV.
- **Helped utilities and grid operators understand the risks and benefits of high penetration PV.** This research has been beneficial to a number of utilities in California, helping to allay some of the concerns associated with this variability. It has also highlighted the conditions under which such variability has the potential to occur: in situations where PV is highly concentrated in one location (i.e., large, single PV facilities or highly concentrated PV on a distribution system). This will have planning benefits at both the transmission and distribution levels.
- **More efficient locating and installation of solar generation resources improving grid economics.** Examples of these improvements include:
  - Improved identification of optimal locations for high penetration levels of PV.
  - Simpler or more streamlined interconnection.
  - Reduction in the need for costly ad hoc load flow studies to determine whether the PV installation creates unacceptable circuit conditions, (2) increasing the value of PV installations by enabling ancillary services such as active power filtering and controlled reactive power support, and (3) improving circuit efficiency and equipment lifetime as a result of those services.
  - Decreased overall cost of solar generation which led to improvements in rates and tariffs.

The Delphi panel reviewers also agreed that the CSI RD&D projects had good potential for providing ratepayer benefits, although their assessment varied across project types. For Grid Integration, the Delphi panelists provided the highest rating of the likelihood of providing ratepayer benefits, rating this as 3.63 on average on the 0-4 scale. This was followed by Solar Technologies (3.25) and Innovative Business Models (3.0).

Economic value to the California grid

The CSI RD&D Program (particularly with the Grid Integration projects) was also successful in providing economic value to the California grid, and Program examples of this are closely tied to those listed above for providing benefits to California ratepayers (see list of above for more details).

Given that the short-term outputs observed so far are consistent with those identified in the logic model (in addition to the large amount of knowledge benefits observed), the Program appears to be on track for achieving the desired medium- and long-term outputs that will lead to increased economic benefit to the grid.

The Delphi panel confirmed this positive outlook for most of the project groups. Not surprisingly, the Grid Integration projects were rated the highest in terms of potential for providing economic value to the grid, with an average rating of 3.75 using the 0-4 scale. This was followed by Solar Technologies projects (3.25) and Innovative Business Models (3.0).

Whether and how the project expands photovoltaic (PV) market opportunities or reduces barriers

A closely related benefit to those described above is the expansion of PV market opportunities and reduction of market barriers. In general, those factors that provide ratepayer benefits or improvements to the grid are in some sense either expanding opportunities and/or reducing barriers. The examples of Program accomplishments listed above, therefore, are also relevant for this criterion. Examples discussed previously that relate specifically to reducing barriers include achievements in streamlining interconnection, improving balance of system and other soft costs, and reducing the upfront costs to solar technology. Additionally, the Grid Integration and Innovative Business Models project groups by definition are designed to expand market opportunities and reduce barriers, and the Grid Integration projects in particular were judged as successful in achieving their goals.

The Delphi panel also confirmed the positive effects of these projects in expanding PV markets and reducing barriers. When asked to rate the positive effects in these areas, the panelists rated the Grid Integration projects 3.88 on average, followed by Solar Technologies (3.38) and Innovative Business Models (2.5).

Institutional and regulatory acceptance of project findings or outcomes

It is still too early to determine the overall effect the CSI RD&D projects will have in terms of institutional and regulatory acceptance, but the early indicators are encouraging. Some important examples of accomplishments already achieved in this area include the following:

- **Improvements to CA Rule 21.** Many of these improvements were derived from CSI RD&D project research, including specific improvements related to PV interconnection limits, project screening, and costs and processes for energy storage systems. In part due to these project outputs, CA Rule 21 was updated in 2016 to include considerations of smart inverters and storage, and included fast tracking of new solar projects meeting specific requirements. These changes helped streamline the review process for interconnection and storage projects, and played a direct role in the improvements to the existing CA Rule 21.

- **Revision and development of new standards for solar inverters and interconnection.** Specific projects have resulted in revisions or information for multiple standards, and testing certifications. These standards are described in the Grid Integration section and include changes to UL1741 SA, IEEE 1547a, IEEE 1547, IEC 61850-7-420 & 520, and IEC 62108.

Furthermore, the significant amount of knowledge benefits—particularly with the amount of follow-on research, new partnerships and publications—are all early indicators of progress that may eventually translate into formal acceptance by institutions and regulatory bodies.

The Delphi panel also believed that at least the Grid Integration projects had the potential for achieving this acceptance, with an average rating of 3.75 on the 0-4 point scale. The Solar Technologies and Innovative Business Models projects were viewed to have less potential in this area (with average ratings of 2.88 and 2.67, respectively), which is not surprising as these projects tended to be more focused on commercialization and management and less oriented toward the regulatory side.

Clean jobs created through CSI RD&D funding

There was limited evidence that the CSI RD&D projects led directly to an increase in clean jobs. This lack of evidence was due in large part to the fact that the evaluation occurred just as these projects were ending, so there was no immediate evidence one way or the other that the Program was having an incremental effect on creating new jobs (a longer-term effect). Given the research focus, any significant new job creation would be expected to occur further in the future once the research results have been more fully integrated and commercialized within the solar industry.

Timing issues not withstanding, there are indications that the CSI RD&D projects have the potential for creating clean jobs in the future. As discussed above, the Program is achieving related positive impacts in terms of providing benefits to California ratepayers and economic value to the grid, which in turn can be expected to eventually result in an increase in jobs. Some of the grantees also reported follow on research and increases in production since the original project that will presumably have positive employment impacts, or at least help sustain current employment levels.

10.4 Recommendations

While the CSI RD&D Program was generally successful in achieving its goals, the results of the evaluation did yield some recommendations for future programs.

- **Sustained program documentation.** Some stakeholders and grantees indicated concern that the Program results have not been disseminated broadly enough and are concerned that the CSI website may not continue to be maintained in the future. The present plan is for the CSI website to remain functional in its current form until December of 2019. We recommend that when the current website is deactivated, the current website contents (including final reports and project documentation) be moved to another established website such as www.calmac.org so that access to the research results can continue.
- **Dissemination of Program results.** There is evidence that some CSI RD&D research has not reached the intended audiences. Two audiences in particular proved challenging: solar hardware and installation firms, and commercial organizations (e.g., builders, retail). To address this, some form of promotion or dissemination of program knowledge in aggregate should be considered—for example, engaging grantees or stakeholders with project knowledge to make presentations at conferences or to key working groups, or write articles in industry publications that summarize key research results and direct readers to the Program website.
- **Program management.** The Program Manager Itron was very successful because it had sound technical knowledge and key industry contacts that allowed it to provide meaningful assistance and make critical networking connections that enhanced program success. Future RD&D programs should have similarly qualified program managers who can provide these types of benefits.
- **Reporting.** We received consistent feedback from the grantees that the reporting requirements were too demanding and difficult to coordinate. To address these concerns, future programs should consider modifying the reporting requirements to be more flexible. Other suggestions from the grantees included providing a report template early in the process, encouraging more stakeholder involvement, and making some draft reports public to elicit more feedback.
- **Best Practices manual.** There are several aspects of the program design that were critical to the success of the Program including careful consideration of project team composition, knowledge dissemination requirements, built-in networking channels and events such as webinars and forums. If there are future RD&D efforts being considered by the CPUC or other agencies, consider working with Itron and CPUC staff to develop a best practices manual that captures the successful elements of program design and management based on the CSI RD&D Program experience.